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Microfossils from Cherts of the Middle Riphean Svetlyi Formation, the Uchur–Maya Region of Siberia, and Their Stratigraphic Significance

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Abstract—Silicified microfossils from the Middle Riphean Svetlyi Formation of the Riphean hypostratotype in the Uchur–Maya region of southeastern Siberia are described for the first time. Cherts are discovered to enclose only simple filamentous and coccoidal microorganisms: hollow sheaths of four hormogonian cyanobacteria species of the *Siphonophycus* genus (*S. robustum*, *S. typicum*, *S. kestron*, and *S. solidum*), filaments of the oscillatorian cyanobacteria *Palaeolyngbya catenata*, and spheroidal microfossils *Myxococcoides* sp. of the unclear taxonomic affinity. The Svetlyi microbiota differs from most assemblages of Middle–Late Riphean (Mesoproterozoic) age by the lack of ellipsoidal representatives of the *Archaeoellipsoides* genus. The low taxonomic diversity of silicified microfossils from the Svetlyi Formation and their organic-walled analogues from the underlying Lower Riphean Omakhta Formation suggest that the successive microfossil assemblages in the section of the Uchur–Maya Region cannot represent a standard for the entire Riphean succession. Description of microfossils from cherts of the Svetlyi Formation is presented.

Key words: microfossils, cyanobacteria, Middle Riphean, standard succession, facies, ecological distribution, environmental paleosettings.

The Siberian hypostratotype of the Riphean in the Uchur–Maya region occupying a huge territory of the southeastern Siberian platform represents one of the most complete pre-Vendian rock successions in northern Eurasia being characterized by successive and representative assemblages of stromatolites and organic-walled microfossils (Semikhatov and Serebryakov, 1983; Semikhatov, 1991; Shenfil', 1991). Nonetheless, the data on silicified microfossils from these deposits are scarce, as chert interbeds and lenses are rare in the thick Riphean and Vendian sequences of the region, and most of them are of the late diagenetic origin. Only several papers available mention finds of silicified remnants of microorganisms in this region, and only one article is dedicated to taxonomic description of microbiota from the Vendian Yudoma Group (Lo, 1980). In the present paper, the more detailed paleontological characteristic of the Riphean hypostratotype is presented, and new data on the representative assemblage of silicified microfossils from the Middle Riphean Svetlyi Formation of the Aimchan Group are discussed.

The Riphean and Vendian deposits of the Uchur–Maya Uplift are divided into six successive groups separated by unconformities and comprising an interval from the Lower Riphean to the uppermost Vendian. These are the Uchur, Aimchan, Kerpyl', Lakhanda, Ui, and Yudoma groups (Fig. 1A), the integral thickness of which exceeds 10 km. The Aimchan Group is distinguished only in the Yudoma–Maya depression and along the eastern periphery of the Uchur–Maya plate. Relatively small exposure areas of the group are concentrated in two separate southeastern and extreme northern parts of the region, where the respective sections are easily correlative owing to persistent lithology of the group and its specific stromatolite assemblages (Semikhatov and Serebryakov, 1983). In the northern part of the region, the Aimchan rocks overly, with the angular unconformity, different horizons of the underlying Uchur Group, and in the south, they rest upon the Archean crystalline basement. The group is overlain by the Totta Formation, the basal unit of the Kerpyl' Group, and represents a large transgressive rhythm composed of two units: the terrigenous Talyn and overlying terrigenous–carbonate Svetlyi formations. The formations are connected by gradual transition due to occurrence of carbonate shale varieties and dolomitic lenses in the uppermost part of the Talyn Formation. The Svetlyi Formation is composed of gray dolomites separated by a member of terrigenous rocks; dolomites enclose abundant columnar stromatolites and also cherty lenses and concretions. The thickness of the formation varies from 100–150 to 500 m.

Based on U–Pb dating of monazite and zircon fractions from the volcanic–plutonic complex unconformably overlain by the Uchur Group, the maximum age limit of the Uchur–Maya Riphean succession is esti-

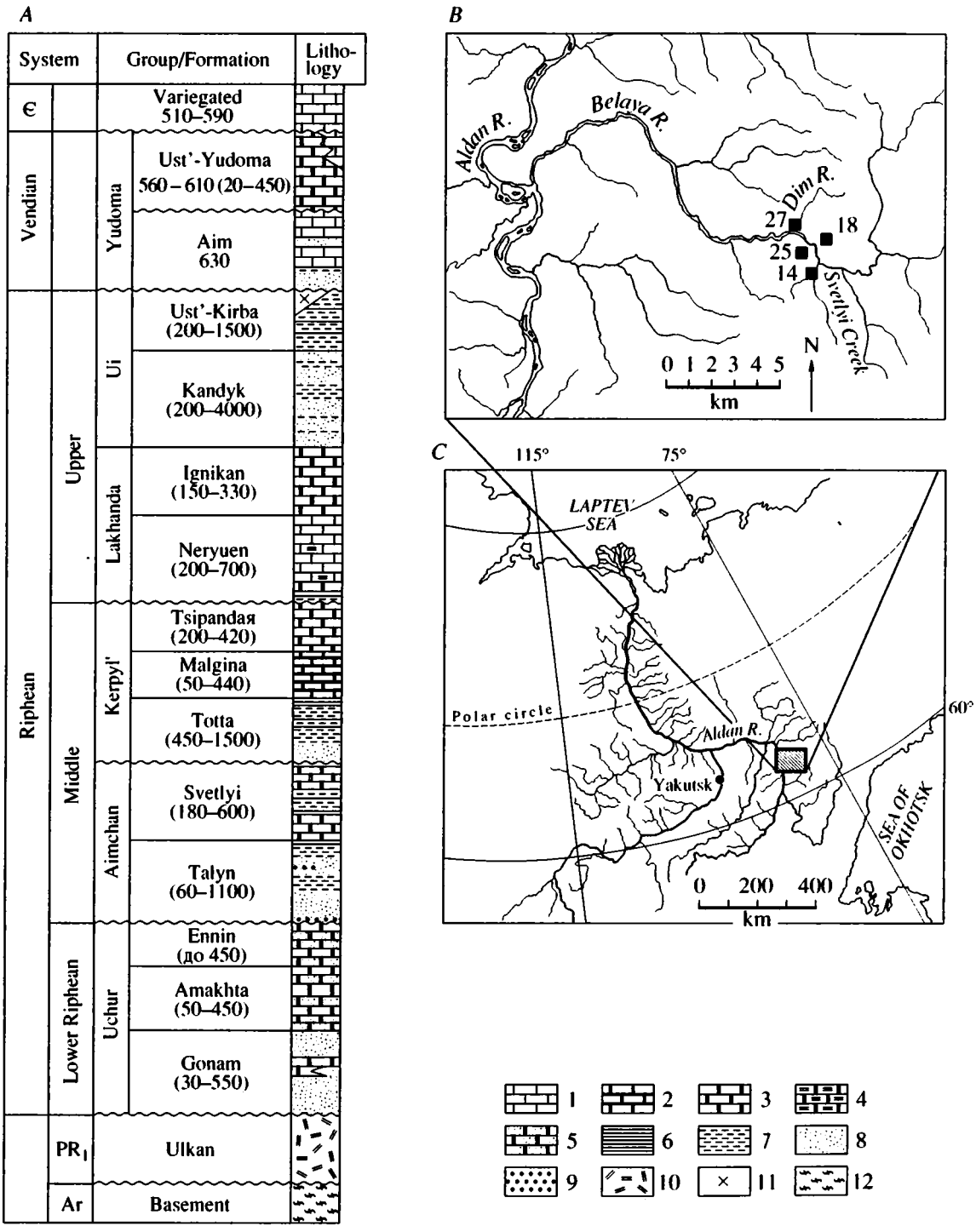

Fig. 1. (A) Riphean and Vendian stratigraphy of the Uchur–Maya region: (1) limestone; (2) variegated laminated algal limestone; (3) dolomite; (4) alternating limestone, dolomite and shale; (5) sandy dolomite; (6) argillite and shale; (7) siltstone; (8) sandstone; (9) gravelstone and conglomerate; (10) acid volcanics and sandstone; (11) ultramafic alkaline intrusive rocks; (12) gneiss and granite-gneiss (after Semikhatov and Serebryakov, 1983). (B) Location of the studied Svetlyi Formation sections in the Belaya River basin; black squares designate exposures of the Svetlyi Formation rocks. (C) The large-scale map of the Belaya River basin.

mated to be approximately 1700 Ma (1703 ± 18, 1727 ± 11, and 1727 ± 6 Ma; Larin *et al.*, 1997). Abundant K–Ar age determinations for minerals of glauconite–illite group from the overlying part of the section revealed the successively decreasing values of 1500–1300, 1260–1200, 1170–860, and 970–870 Ma for the Uchur, Aimchan, Kerpyl', Lakhanda groups, respectively (Semikhatov and Serebryakov, 1983; Semi-

khatov *et al.*, 1989; and references therein). Initially, these dates were interpreted as corresponding to deposition time of the listed rock units. Nonetheless, at least some of these dates conflict with the results of recent U–Pb age determinations for baddeleyite from basic sills intruding the Lakhanda and Ui groups. The last dates are 974 ± 7 and 1005 ± 4 Ma (Rainbird *et al.*, 1998) and Sm–Nd isochron age of the same sills is 948 ± 18 Ma (Pavlov *et al.*, 1992). The maximum age limit of the Kerpyl' Group determined using detrital zircons from the Totta Formation is estimated to be 1300 ± 5 Ma (Khudolei *et al.*, 1998). Thus, the available isotopic–geochronological K–Ar data suggest that the Aimchan Group is younger than 1300 Ma and older than 1100 Ma and, consequently, it should be referred to the lower part of the Middle Riphean. The paleontological evidence also supports this conclusion.

Stromatolites form five successive and taxonomically different assemblages in the sedimentary section of the Uchur–Maya Uplift. The Svetlyi assemblage contains several characteristic Middle Riphean taxa, including *Baicalia aborigena* Schap. described from the Middle Riphean stratotype of the southern Urals (Keller, 1982; Semikhatov and Serebryakov, 1983), whereas the underlying Uchur Group encloses only the Early Riphean forms (*Omachtenia omachtensis* inclusive) and the overlying Lakhanda Group hosts diverse index species of early Late Riphean age (Shapovalova, 1974; Semikhatov and Serebryakov, 1983; Semikhatov, 1991; Shenfil', 1991).

The successive microfossil assemblages from the Riphean section of the Uchur–Maya region show sharp changes at the base of the Kerpyl' Group and at the basal levels of the Lakhanda and Ui groups (Pyatiletov, 1988; Veis, 1988; Veis and Semikhatov, 1989; Hermann, 1990; Veis and Petrov, 1994; Veis *et al.*, 1998). The oldest assemblage of organic-walled microfossils occurring in the Omakhta Formation of the Uchur Group consists of small, morphologically simple filamentous and coccoidal forms of a wide stratigraphic range (Veis and Semikhatov, 1989). The Totta Formation of the Kerpyl' Group encloses a much more diverse microfossil assemblage (Veis, 1988; Veis and Petrov, 1994; Veis *et al.*, 1998) that includes several stratigraphically important taxons (first of all *Chuaria, Ostiana, Ulophyton, Majaphyton*, and others). Nevertheless, the unambiguous Late Riphean index species are unknown in this assemblage. In addition, similar assemblages were discovered in the Lower Riphean deposits, for instance, in the Roper Group of Australia (Peat *et al.*, 1978), Ust'-Il'ya and Kotuikan formations of the Anabar Uplift (Veis and Vorob'eva, 1992), and in some other sedimentary successions. The last discovery decreases stratigraphic significance of the pre-Totta level of changes in succession of organic-walled microfossil assemblages of the Uchur–Maya Uplift virtually imparting a regional status to this level. The distinct regional manifestation of the latter is probably related to some others, not evolutionary factors (this problem will be considered in more detail below during the analysis of the biostratigraphic significance of microbiota from the Svetlyi Formation). The next distinct boundary in succession of organic-walled microfossil assemblages is known in basal layers of the Neryuen Formation of the Lakhanda Group. The noteworthy feature of the corresponding microfossil assemblage is presence of acanthomorphic acritarchs of the *Trachyhystrichosphaera* genus in association with some other taxa complex in structure and characteristic of the Upper Riphean deposits (Veis, 1988; Yankauskas *et al.*, 1989; Semikhatov, 1991; Veis and Petrov, 1994; Veis *et al.*, 1998; and others).

Thus, isotope age determinations and available data on distribution of stromatolites and organic-walled microfossils in the sedimentary succession of the Uchur–Maya region indicate that the Middle–Upper Riphean boundary is located there between the Tsipanda and Neryuen formations, and that the Aimchan Group is of the early Middle Riphean age.

Cloud *et al.* (1977) were first to mention silicified microfossils from the Svetlyi Formation, but they did not publish either the description or pictures of the discovered microorganisms. Later, Kolosov (1982) described a single silicified microfossil form this formation that was identified as *Svetlaphyton parallelum* Kolosov representing, according to the initial description, clusters of parallel filaments emerging from the substrate and located 2.0–3.0 to 4.0–6.0 μm apart. These data did not give any idea of the Svetlyi microbiota composition.

To fill this gap in the knowledge, I sampled cherts from the lower and upper members of the formation type sections during my field work of 1990 in the Belaya River basin (Fig. 1B). Samples were collected from the river valley walls at the following localities: (1) the right wall near the Dim River mouth (Exposure 27, the lower member, Samples 4689/31–4689/34); (2) the left wall downstream of the Salar River mouth (Exposure 18, the lower member, Sample 4689/21); (3) the left wall downstream of the Trekhgorka River mouth (Exposure 25, the lower member, Samples 4689/23–4689/25; the upper carbonate member, Samples 4689/26–4689/30); and (4) the Svetlyi Creek valley, 3.5 km upstream of its mouth (Exposure 14, the lower member of the formation stratotype, Samples 4689/15–4689/20). The formation thickness in the listed localities varies from 310–330 m in the Svetlyi Creek valley to 160–175 m near the Dim River mouth. The variably preserved microfossils were discovered from both carbonate members of the Svetlyi Formation in all the exposures, however, differences in composition of microbiota from different horizons are undetected.

The microbiota from the Svetlyi Formation appeared to be of a low taxonomic diversity and is represented by almost exclusively aseptate hollow filamentous forms of the genus *Siphonophycus*, namely by *S. robustum, S. typicum, S. kestron*, and *S. solidum* hav-

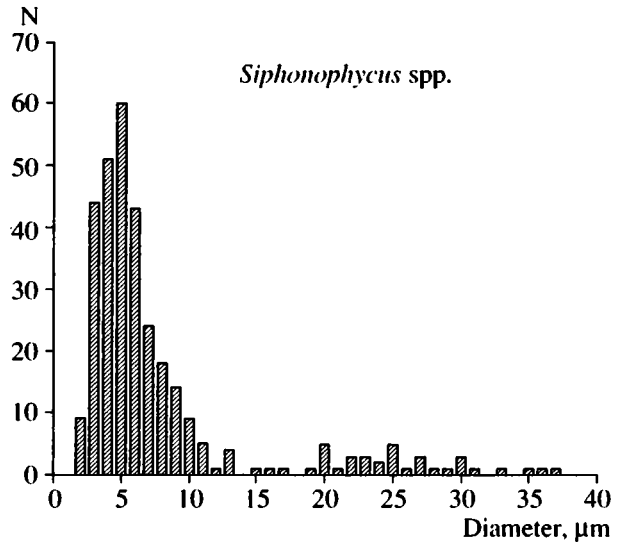

Fig. 2. Histogram demonstrating distribution of diameter sizes of hollow sheaths that represent four species of the *Siphonophycus* genus in the Svetlyi microbiota (N, number of measurements).

ing diameter ranges 2.0–4.0, 4.0–8.0, 8.0–16.0, and 16.0–30.0 μm, respectively (Fig. 2). These species occur mainly in the form of mats, where filaments of several to several thousands individuals are arranged in the parallel or chaotic manner (Plate, Figs. 1–3, 7, 11, and 12). It should be noted that the form described by Kolosov as *Svetlaphyton parallelum* represents probably *Siphonophycus* sheaths arranged in parallel within their colonies. Mat-forming species of filamentous microfossils of the genus *Siphonophycus* are reasonably interpreted as fossilized hollow sheaths of hormogonian cyanobacteria of the so-called LPP type (*Lyngbya–Phormidium–Plectonema*). In addition, the lower member of the Svetlyi Formation (Sample 4689/18) yields filamentous remains of *Palaeolyngbya catenata*, the multicellular trichomes composed of flattened–cylindrical cells 14.0–15.0 μm across and 2.0–5.5 μm high, which are surrounded by transparent sheaths 19.0–22.5 μm in diameter and less the 1 μm thick (Plate, Figs. 4–6). *Palaeolyngbya catenata* probably represents the fossilized filaments of those hormogonian cyanobacteria species whose separately preserved hollow sheaths are determined as *Siphonophycus solidum*.

Coccoidal forms are scarce amid the studied microfossils being represented by separate poorly preserved spheroids 10.0–25.0 μm in diameter. These forms apparently are remains of originally smooth coccoidal microorganisms of a probable planktonic origin, which can be referred to the form genus *Myxococcoides* (Plate, Figs. 8–10). It is noteworthy that the spheroid surface sometimes bears spine-shaped projections probably of the secondary origin. Similar pseudospiny microfossils are described from several silicified microbiotas of the Middle and Early Riphean age (Sergeev, 1992; Sergeev *et al.*, 1995).

In addition to microfossils, the silicified carbonate rocks of the Svetlyi Formation yield the so-called carbonate precipitates—the laminated sedimentary structures resembling stromatolites in appearance, but having a chemogenic or mixed biochemogenic origin (Plate, Figs. 13–15). These structures are widespread in the Archean, Lower Proterozoic, Lower and Middle Riphean (Mesoproterozoic) sedimentary successions (as well as in the uppermost Mesoproterozoic, since I observed them in the Sukhaya Tunguska Formation of the Turukhansk Uplift). On the contrary, they are virtually missing from the Upper Riphean deposits (Semikhatov and Raaben, 1996; Bartley *et al.*, in press).

Inasmuch as sedimentary structures associated with microfossils have not been analyzed yet using sophisticated methods, the unambiguous interpretation of the facies affinity of the Svetlyi microbiota is impossible. Nevertheless, composition and peculiar relationships of microfossils with sedimentary structures elucidate to a certain extent the ecological–facial habitat settings of Svetlyi microorganisms. Under the microscope, cyanobacterial mats of hollow *Siphonophycus* sheaths either occupy the entire observation field, or are present in isometric rounded microclasts to several dozens of microns in size. Similar monotaxonic mats composed of hollow *Siphonophycus* sheaths occur in either the upper subtidal, or upper intertidal to supratidal zones (Knoll *et al.*, 1991; Sergeev *et al.*, 1997). Therefore, it is quite natural to assume that dolomites of the Svetlyi Formation accumulated precisely in these facies settings. In this connection, it is noteworthy that entophysaledacean cyanobacteria typical of the pre-Upper Riphean sequences and dwelling in the lower intertidal zone are missing from the considered microbiota. This can be explained as well by the subtidal or, to the contrary, by upper intertidal–supratidal accumulation setting of layers with microfossils. On the other hand, the study on facies distribution of microbiota in the Middle Riphean Sukhaya Tunguska Formation of the Turukhansk Uplift demonstrated that the Precambrian ecological niches of these cyanobacterial communities slightly differed from the present-day ones, as they colonized the upper subtidal zone as well (Petrov *et al.*, 1995). It should be also noted that the almost monogeneric composition of the Svetlyi microbiota suggests that habitat environments were sufficiently unfavorable for colonization by microorganisms. As is established by Golubic (1976), cyanobacterial mats formed by hormogonian algae are characterized by the minimal taxonomic diversity of constituent coccoidal microorganisms under the least favorable conditions and, in contrast, their diversity increases in parallel with amelioration of habitat environments.

Despite the low diversity, the Svetlyi microbiota is interesting in the context of the dominant defined recently in the Lower–Middle Riphean microbiotas,

and also as a member of the succession of microfossil assemblages of the Uchur–Maya region, because some researchers consider it as the standard one for the entire Riphean section. The Lower–Middle Riphean (Mesoproterozoic) deposits are typically characterized by preponderant ellipsoidal microfossils of the *Archaeoellipsoides* genus that is interpreted to represent the fossilized akinetes of the hormogonian *Anabaena*-like cyanobacteria (Knoll and Sergeev, 1995; Sergeev *et al.*, 1995; Sergeev, 1997a, 1997b). Their assemblage is not a sole component of the Early–Middle Riphean microbiotas, as cherts of many carbonate successions enclose only mats formed by sheaths of *Siphonophycus* forms enclosing remains of coccoidal microorganisms (Sergeev, 1992). The dominant assemblages of silicified *Archaeoellipsoides* forms are usually accompanied by inorganic carbonate precipitates subdivided into several types. Most common amid the latter are microlaminated and radial–fibrous aragonite fans (Bartley *et al.*, in press). It is assumed that akinete-forming nostocalean cyanobacteria colonized the lower intertidal zone of the pre-Late Riphean basins lacking the competitive eukaryotic microorganisms. Moreover, development of akinetes was stimulated by the high calcium carbonate content in the water that also resulted in formation of sedimentary precipitates (Golubic, 1995; Knoll and Sergeev, 1995; Sergeev *et al.*, 1995). Similar precipitates are abundant in silicified dolomites of the Svetlyi Formation where they are preserved, like in several other Proterozoic cherty–carbonate sequences, owing to the early silicification of primary sedimentary structures eliminated by subsequent dolomitization in the other parts of the section. Nevertheless, none of fragmentary or intact ellipsoidal microfossils has been discovered in the Svetlyi Formation. This phenomenon can be explained most simply by different facies affinities of layers with microfossils: as it is assumed above, microorganisms characteristic of the Svetlyi Formation populated the upper subtidal, or upper intertidal to supratidal zones, whereas most of microfossil assemblages with *Archaeoellipsoides* and *Eoenthophysalis* forms include inhabitants of the lower intertidal zone.

A similar lateral differentiation can also be caused, in addition to local facies-dependent distribution of microorganisms in ancient basins, by global factors, for instance by the climatic zoning. The matter is that the well-expressed microphytological boundary at the base of the Totta Formation is, as mentioned above, of a regional scale being unexpressed even in the adjacent Anabar Uplift. Simultaneously, the oldest microfossil assemblage of the Uchur–Maya region represented in general by morphologically very simple and small microorganisms is significantly less diverse as compared with the coeval organic-walled and silicified microbiotas. It was probably dependent on the ecological–facial habitat conditions of microfossils in the basin during the Omakhta time, as the terrigenous–carbonate rocks of the Omakhta Formation are characterized by a high lateral variability, contain abundant horizons with mud cracks and glyptomorphs after halite and gypsum, and are interpreted to represent sediments accumulated in the upper subtidal and intertidal zones of a shallow epicontinental basin (Semikhatov and Serebryakov, 1983; Knoll and Semikhatov, 1998). The assemblage of silicified microfossils from the Svetlyi Formation is also extremely impoverished as compared with coeval and older microbiotas enclosed in cherts (Hofmann and Schopf, 1983; Knoll *et al.*, 1988; Sergeev, 1992; Sergeev *et al.*, 1995; and others). This leads to assumption that habitat environments on the Uchur–Maya Uplift during the pre-Totta time were generally unfavorable for microorganisms. The analysis of factors, which could inhibit metabolic activity of ancient microorganisms, is beyond the scope of this paper, but it is clear that microfossil assemblages from the Lower and lower Middle Riphean deposits of the Uchur–Maya Uplift, which are so impoverished in composition, can hardly represent a standard succession for the whole Riphean stage of development of microorganisms (despite the representative Upper Riphean microbiotas from this region, which are known as best microbiotas of the world). This probably explains the fact that correlation by Veis (Veis, 1988; Veis and Petrov, 1994; Veis *et al.*, 1998; and others) who based it on distribution of different morphotypes of ancient microfossils in the Riphean deposits, first of all on their succession in the Uchur–Maya section, is in conflict with correlation substantiated by isotopic–geochronological, chemostratigraphic, and biostratigraphic methods. Contradictions in this correlation are evident when we consider not only the remote sections of other continents, but also the reference sections of northern Eurasia, the neighboring Anabar Uplift included (Semikhatov, 1995; Sergeev *et al.*, 1995). Consequently, the generalized composition of typical Middle and Late Riphean microfossils should be inferred from data on their more representative assemblages from other regions.

In general, the silicified microbiota from the Svetlyi Formation supplement paleontological characteristics of the Riphean deposits in the Uchur–Maya region providing the valuable information on the composition and habitat environments of Middle Riphean microorganisms.

Description of silicified microfossils from the Svetlyi Formation is presented below. They were studied, using common procedures, in standard petrographic thin-sections under transmitted light and photographed using microscope REM-5 and Micrat-300 film. Positions of microfossils were marked by points on the narrow paper band attached to the edge of the thin-section. All studied and described samples are stored at the Geological Institute of Russian Academy of Sciences, collection no. 4698.

DESCRIPTION OF MICROFOSSILS

Kingdom Eubacteria Woese et Fox, 1977

Phylum Cyanobacteria Stanier *et al.*, 1978

Class Hormogoneae

Order Oscillatoriales

Family Oscillatoriaceae (S.F. Gray) Dumortier ex Kirchner, 1898

Genus *Palaeolyngbya* Schopf, 1968

Type species. *Palaeolyngbya barghoorniana* Schopf, 1968

Palaeolyngbya catenata Hermann, 1974

Plate, Figs. 4–6

Palaeolyngbya catenata Hermann, 1974, pp. 8–9, Plate 6, Fig. 5; Butterfield *et al.*, 1994, p. 61, Figs. 25 F–G.

Palaeolyngbya maxima Zhang Y., 1981, p. 495, Plate 2, Figs. 4, 6, 7; Sergeev *et al.*, 1994, p. 3, Plate III, Fig. 8.

Oscillatoriopsis robusta Horodyski et Donaldson, 1980, pp. 149–152, Fig. 13H.

Doushantuonema peatii Zhang Z., 1981, p. 204, Plate 1a–c.

Scalariphycus tianzimiaoensis Song, 1982, p. 218, Plate 32, Figs. 9–11.

Holotype: paleontological collection of the Institute of Precambrian Geology and Geochronology, St. Petersburg, Russia, specimen 49/23; Upper Riphean, Miroedikha Formation, Turuhansk Uplift, Siberia.

Description. Monotype nonbranching trichome surrounded by distinct external sheath; the filament diameter is 19.0 to 22.5 μm, the length up to 150 μm. The trichome consists of discoid-cylindrical cells 14.0–15.0 μm wide and 2.0–5.5 μm long. The width/length ratio of cells varies from 3 to 7. Cross-walls are distinct, but neighboring cells of the trichome are separated by spaces. Side walls and cross-walls are transparent, fine-grained, and less than 0.5 μm thick. The external sheath is transparent, nonlaminated, less than 0.5 μm thick.

Comparison. *Palaeolyngbya catenata* differs from other species of the *Palaeolyngbya* genus in larger dimensions of trichome cells.

Remarks. We follow classification proposed by Butterfield *et al.*, (1994) including the above-mentioned synonyms.

Distribution. The species is widespread in the Riphean and Vendian deposits.

Material: one filament.

Order Nostocales or Oscillatoriales

Genus *Siphonophycus* Schopf emend. Knoll et Golubic, emend. Knoll *et al.*, 1991.

Type species. *Siphonophycus kestron* Schopf, 1968

Siphonophycus robustum (Schopf) emend. Knoll et Golubic, 1979.

Plate, Figs. 1, 2, 7, 11, 12.

Eomycetopsis robusta Schopf, 1968, p. 685, Plate 82, Figs. 2, 3; Plate 83, Figs. 1–4; Knoll and Golubic, 1979, p. 149, Figs. 4A, 4B.

Eomycetopsis filiformis Schopf, 1968, p. 685, 686; Plate 82, Figs. 1, 4; Plate 83, Figs. 5–8.

Siphonophycus robustum Knoll, Swett et Mark, 1991, p. 565, Figs. 10.3, 10.5 (the complete synonymy is given in Sergeev, 1992, and in Butterfield *et al.*, 1994).

Holotype: paleobotanical collection of the Harvard University, specimen 58491, thin section Bit/Spr 10–1; coordinates 36.7 × 107.6; Upper Riphean, Bitter-Springs Formation, Australia.

Description. Nonbranching aseptate hollow tubular structures usually forming colonies composed of many hundreds and thousands of interwoven filaments, but sometimes occurring as separate specimens. The diameter of tubular structures varies from 2.0 to 4.0 μm; the external surface and side wall varies from smooth to fine-grained; the thickness of the latter is less than 0.5 μm. Tubular structures in colonies are frequently oriented in parallel or perpendicularly to lamination.

Remarks. Based on formal criteria, Butterfield *et al.* (1994) subdivided hollow filamentous forms referred to the *Siphonophycus* genus into several species: *Siphonophycus thulenema* Butterfield, 1994, *S. septatum* (Schopf, 1968), *S. robustum* (Schopf, 1968), *S. typicum* (Hermann, 1974), *S. kestron* Schopf, 1968, and *S. solidum* (Golub, 1979) having the sheath diameter of about 0.5, 1.0–2.0, 2.0–4.0, 4.0–8.0, 8.0–16.0, and 16.0–32.0 μm, respectively. This classification turned out to be sufficiently convenient in practice and is followed in this paper. *S. robustum* is a main mat-forming species in many Proterozoic assemblages of benthic microorganisms.

Distribution. The species occurs almost in all Proterozoic microfossil assemblages.

Material: several hundreds of specimens.

Siphonophycus typicum (Hermann) comb. Butterfield, 1994

Plate, Figs. 1, 2, 7, 11, 12

Leiotrichoides typicus Hermann, 1974, p. 7, Plate VI, Figs. 1–2.

Siphonophycus inornatum Zhang, 1981, pp. 491–493, Plate 1, Figs. 3–5.

Eomycetopsis lata Golovenok and Belova, 1985, pp. 94–96, Plate VII, Fig. 4; Yankauskas *et al.*, 1989, pp. 106–107, Plate XX, Fig. 4.

Siphonophycus typicum Butterfield, 1994, in Butterfield *et al.*, 1994, pp. 66–67, Figs. 23B–D, 26B, H, I (the complete synonymy is given in Butterfield *et al.*, 1994).

Holotype: paleontological collection of the Institute of Precambrian Geology and Geochronology, St. Petersburg, Russia, specimen 49/2T; Upper Riphean, Miroedikha Formation, Turuhansk Uplift, Siberia.

Description. Nonbranching aseptate hollow tubular structures usually forming colonies of many hundreds and thousands of interwoven filaments, but sometimes

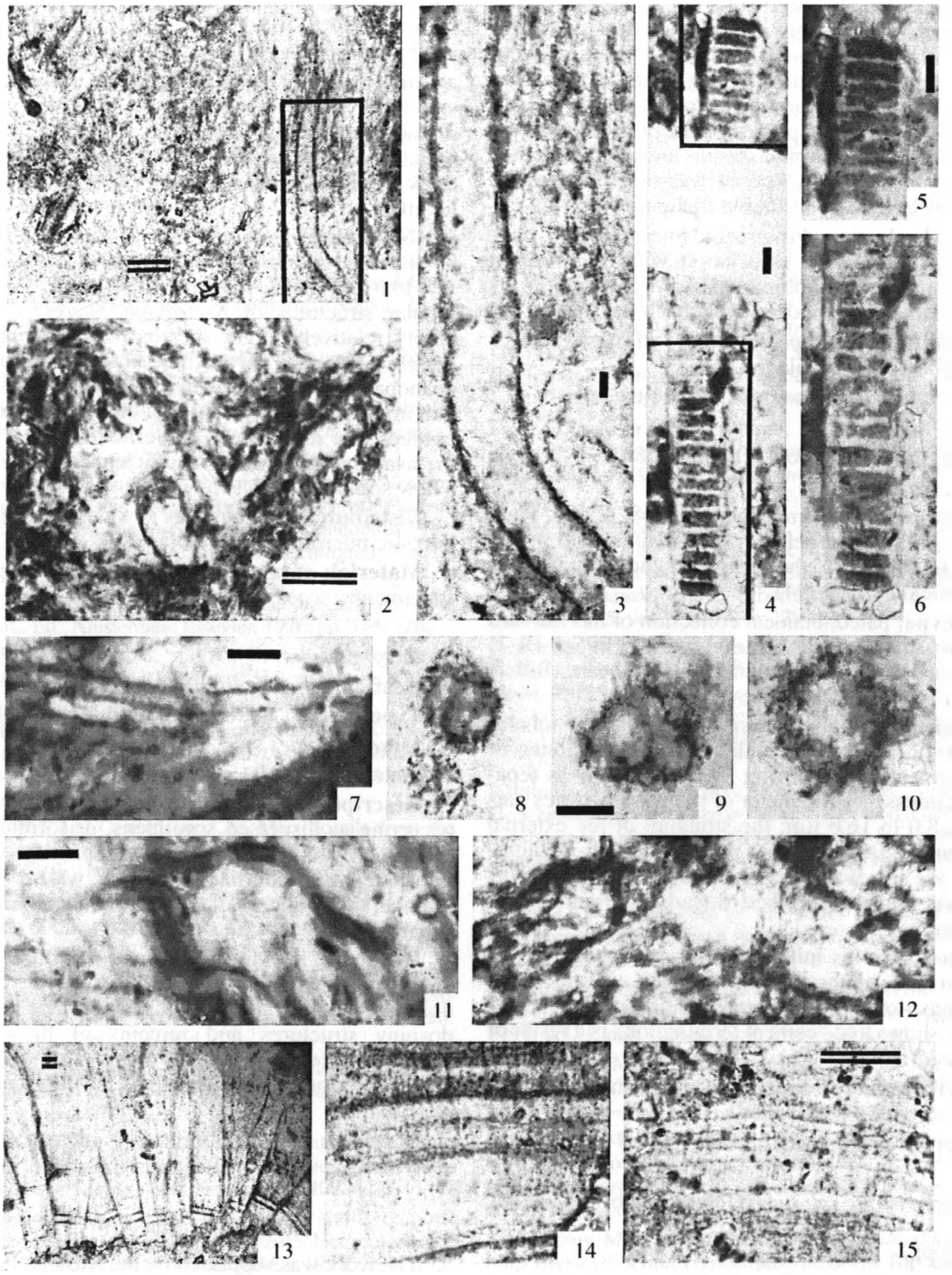

Plate. Silicified microfossils from the Svetlyi Formation.

(1–3) sheaths of *Siphonophycus solidum* in colonies formed by sheaths of *S. robustum*, *S. typicum*, and *S. kestron*: (1, 3, rectangle in 1) Sample 4698-18, thin section 837-98, point 8, specimen GIN 650; (2) Sample 4698-18, thin section 846-98, point 4, specimen GIN 651; (4, 5, upper rectangle in 4), (6, lower rectangle in 4) *Palaeolyngbya catenata*, Sample 4689-18, thin section 788-98, point 10, specimen GIN 652; (7, 11, 12) sheaths of *Siphonophycus robustum* and *S. typicum*, Sample 4689-18, thin section 788-98: (7) point 9, specimen GIN 653; (11) point 9', specimen GIN 654; (12) point 9", specimen GIN 655; (8–10) *Myxococcoides* sp., Sample 4689-30, thin section 803-98: (8) point 5, specimen GIN 656; (9) point 8, specimen GIN 657; (10) point 1, specimen GIN 658; (13–15) sedimentary precipitates, Sample 4689-28, thin section 847-98: (13) point 14, (15) point 1.

Single bar is equal to 10 μm and double bar, to 50 μm. Bar for Figs. 6 is shown in Fig 5, for Figs. 8 and 10 in Fig. 9, for Fig. 12 in Fig. 11, and for Figs. 13 and 14, in Fig. 15.

occurring as separate specimens. The diameter of tubular structures varies from 4.0 to 8.0 μm; the structure of the external surface and side wall varies from smooth to fine-grained; the thickness of the latter is less than 0.5 μm. Tubular structures in colonies are frequently oriented in parallel or perpendicularly to lamination. Cross-walls are missing but sheaths are sometimes broken into several closely spaced fragments with sharp edges; they externally resemble trichomes.

Remarks. In many Proterozoic microbiotas, *S. typicum* occurs usually in association with *S. robustum* sheaths similarly to combination of *Lyngbya* and *Phormidium* filaments in modern cyanobacterial mats.

Distribution. The species occurs in most Proterozoic microfossil assemblages.

Material: several hundreds of specimens.

Siphonophycus kestron Schopf, 1968.

Plate, Fig. 1.

Siphonophycus kestron Schopf, 1968, p. 671, Plate 80, Figs. 1–3; Butterfield, 1994, in Butterfield *et al.*, 1994, p. 67, Fig. 21D (the complete synonymy is given in Butterfield *et al.*, 1994).

Holotype: paleobotanical collection of the Harvard University, specimen 58491, thin section Bit/Spr 10–1; coordinates 36.7 × 107.6; Upper Riphean, Bitter-Springs Formation, Australia.

Description Nonbranching aseptate hollow tubular structures open from both ends and forming colonies of many filaments, or occurring more frequently as separate specimens. The diameter of tubular structures varies from 8.0 to 16.0 μm; the structure of the external surface and side wall varies from smooth to medium-grained; the side wall thickness is 0.5–1.0 μm. Sheaths sometimes enclose shrinked thread-like remnants of trichomes.

Remarks. In his initial description, Schopf (1968) indicated that sheaths of *S. kestron* have a distinct conical termination. However, examination of the species holotype shows that "conical termination" is a result of sheath deformation.

Distribution. The species occurs in many Proterozoic microfossil assemblages.

Material: several specimens.

Siphonophycus solidum (Golub) comb. Butterfield, 1994

Plate, Figs. 1–3.

Omalophyma solida Golub, 1979, p. 151, Plate 31, Figs. 1–4, 7.

Siphonophycus solidum Butterfield *et al.*, 1994, p. 67, Figs. 25H-1, 27D (the complete synonymy is given in Butterfield *et al.*, 1994).

Holotype: collection of the All-Russian Institute of Geology (VSEGEI), St. Petersburg, Russia, specimen R-163/3; Upper Vendian ("Neoproterozoic-III"), Smolensk Formation (Rudnyanskaya Borehole, upper part, interval 747.8–763.3 m); East European platform, northern Orsha depression, Russia.

Description. Nonbranching aseptate hollow tubular structures occurring mainly as separate specimens. The diameter of tubular structures is 16.0–38.0 μm; the structure of external surface and side wall about 1.0 μm thick is smooth or fine-grained. The maximum filament length is up to 200 μm (incomplete specimen).

Remarks. *Siphonophycus solidum* occurs usually as dispersed specimens in colonies of tightly interwoven filaments of *S. robustum* and *S. typicum*. Hollow tubular structures of *S. solidum* represent probably empty relatively larger sheaths of monotrichomatous *Lyngbya*-like or polytrichomatous *Microcoleus*-like cyanobacterial filaments. In the Svetlyi microbiota, the maximum diameter of sheaths of this species slightly exceeds that reported by Butterfield *et al.* (1994), but the available material is insufficient for distinguishing a new species.

Distribution. The species is widespread in the Proterozoic microfossil assemblages.

Material: several hundreds of variably preserved specimens.

Incertae sedis

Genus *Myxococcoides* Schopf, 1968

Type species. *Myxococcoides minor* Schopf, 1968

Myxococcoides sp.

Plate, Figs. 8–10.

Description. Spheroids with the one-layer envelope occurring as dispersed specimens, or forming diades, triades, and flat tetrads; sheaths of spheroids are semitransparent, the external surface and wall are medium-grained; the thickness of the latter is about 1.0 μm. The spheroid diameter varies from 10.0 to 25.0 μm.

Remarks. Envelopes of some *Myxococcoides* sp. spheroids are deformed probably by the growth of dolomite crystals; as a result, their surface bears pseudospiny structures and remains of these initially smooth microorganisms have an external similarity with acanthomorphic acritarchs of the genus *Micrhystridium*.

Material: Several dozens of moderately preserved specimens.

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Biostratigraphy of the Frasnian Stage by Radiolarian Evidence

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Abstract—Revising Frasnian radiolarians, we established three new radiolarian zones within this stage. These are the *Helenifore gogoense–Retisphaera concinna* Zone of the lower Frasnian, *Moskovistella allbororum–Ceratoikiscum ukhtensis* Zone of the middle Frasnian, and *Bientactinosphaera egindyensis–Polyentactinia circumretia* Zone of the upper Frasnian.

Key words: radiolarians, Frasnian Stage, biostratigraphy.

INVESTIGATION HISTORY

First data on Devonian radiolarians were reported by Rüst (1891–1892) who described, in addition to Paleozoic radiolarians of Germany, numerous genera and species of radiolarians recovered in Russia from Devonian jaspers of the Mt. Yukali on the eastern slope of the Urals (Fig. 1).[1] New identifications of Devonian radiolarians from the eastern slope of the Urals were carried out by Amon (1995) a hundred years later.

The diverse (54 species) assemblage of the Devonian radiolarians from the volcanogenic–cherty Varrimi Formation in the New South Wales, Australia, was described by Hinde (1899) at the end of the last century, but its Givetian age was established just now (Aitchison, 1990; Aitchison and Stratford, 1997). Certain forms described by Hinde were found in the deposits of the Domanik Formation of the middle Frasnian in the Volga–Urals region (Bykova, 1955) and in the Timan–Pechora province (Maksimova, 1970; Afanas'eva, 1997; Afanas'eva and Mikhailova, 1995a, 1995b). These forms were also recognized in the Frasnian deposits of the northern Mugodzhary region (Nazarov, 1973; 1975; 1988).

Presence of radiolarians in Devonian deposits of the southern Urals and northern Mugodzhary was originally noted by Teodorovich (1935), Strakhov (1939), and Balaev (1946). However, skeletons of the Frasnian radiolarians were macerated from the carbonate concretions of the Yegindy Formation of the northern Mugodzhary and studied in detail by Nazarov only in the middle of the 1970s (Nazarov, 1973; 1975).

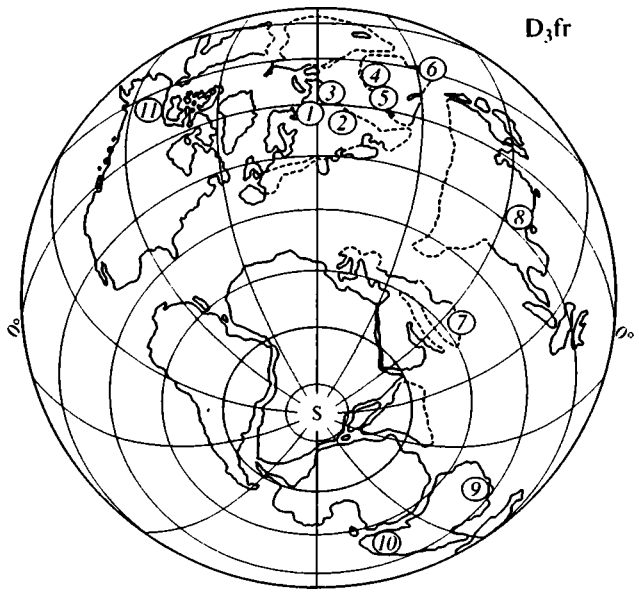
In his works, Nazarov (1973, 1975, 1981, 1984, 1988) demonstrated that the Frasnian radiolarian assemblages are distributed in the following rock units: in limestone interbeds of the Evtropiny Formation exposed at the Evtropiny Noski site of the Un'ya River, the northern Urals; in carbonate concretions of the Yegindy Formation exposed along the Aitpaika River of the northern Mugodzhary; in red jaspers exposed on the northern slope of the Alai Ridge in southern Kyrgyzstan; and in green-gray to purple cherty siltstones and jaspers of the ophiolite sequence of the Chara zone in eastern Kazakhstan.

Several species of Frasnian radiolarians from deposits of the Volga–Urals province were described by Bykova (1955; Table XX–XXIII) who identified the following species in sections of the Domanik cherty–carbonate rocks: *Staurolonche davidi* Hinde, *Xiphosphaera echinatum* (Hinde), *Dorysphaera domanicensis* Bykova, *Trilonche vetusta* Hinde, *Plagoniscus(?)* sp., *Acanthosphaera australis* Hinde, *Cenosphaera scitula* Hinde.[2]

Presence of abundant radiolarians in the Domanik Formation stratotype in the eponymous river valley, the Ukhta region of the Timan–Pechora province, was established by T.I. Kushnareva as early as in 1959. First photographs of the Domanik radiolarians (without classification and description) were published by Maksimova (1970; Table 5), and Nazarov (1975, 1988) preliminarily identified them later. Judging from the photographs presented in these papers, radiolarians belong

[1] The occurrence localities of Frasnian radiolarians that are known at present are shown on the scheme of the Late Devonian global reconstruction of continents and oceans by Khramov *et al.* (1982).

[2] The revision of species identified by Bykova showed that they are analogous to radiolarian species from the Domanik deposits of the southern Timan–Pechora basin, namely to *Bientactinosphaera grandis* (Nazarov); *Radiobisphaera menneri* Afanasieva; *Radiobisphaera domanicensis* (Bykova); *Bientactinosphaera variacanthina* (Foreman); *Palaeothalommus quadriramosum* (Foreman), *Astroentactinia biaciculata* Nazarov; *Astroentactinia crassata* Nazarov, respectively.



Geographic distribution of Frasnian radiolarians: (*1*) Timan-Pechora province; (*2*) Volga–Urals province; (*3*) northern Urals (western slope); (*4*) central Urals (eastern slope); (*5*) northern Mugodzhary; (*6*) eastern Kazakhstan, the Chara zone; (*7*) southern Kazakhstan, the Alai Ridge; (*8*) China, east-southeastern Guangxi province; (*9*) Western Australia, Canning basin; (*10*) Eastern Australia, New England Ridge; (*11*) eastern Alaska.

to the middle Frasnian assemblage of *Radiobisphaera domanicensis* (Bykova), *Bientactinosphaera grandis* (Nazarov), *B. polyacanthina* (Foreman), *Astroentactinia biaciculata* Nazarov, and *A. tantilla* Nazarov considered below.

The comprehensive revision of the abundant radiolarians from the middle Frasnian Domanik Formation of the Timan–Pechora province of Russia gave rise to the new classification of Paleozoic radiolarians that was used for the detailed biostratigraphy of oil- and gas-bearing deposits and in reconstruction of specific environments in the Domanik basin, which were favorable for the organic matter concentration (Afanas'eva, 1994, 1996, 2000; Afanas'eva and Mikhailova, 1994; 1995a, 1995b; 1997; 1998; Vishnevskaya *et al.*, 1993; Afanas'eva, 1997, 1998; Afanas'eva and Mikhailova, 1994, 1995).

Nazarov and Ormiston (1983) were first to describe an assemblage of Frasnian radiolarians (19 species) recovered from carbonate concretions occurring in the upper part of the Gogo Formation in the Canning basin of Western Australia, where this unit consists of clayey–slate beds intercalated with limestone interbeds, lenses, and concretions. Aitchison (1993) described new species of echinate radiolarians (57 species) from the lower part (Frasnian Stage) of the Gogo Formation, and Won (1997a, 1997b) described 84 new species and subspecies of spherical radiolarians.

Ishiga *et al.* (1987) distinguished an assemblage of Frasnian radiolarians in the clay–shale sequence of the Hastings Block in the New England Fold Belt, Western Australia.

In 1991, Y.-X. Li and Y.-J. Wang described for the first time Frasnian radiolarians of China, which were recovered from the cherty rocks of the Liukiang Formation in the east-southeast of the Guangxi province. Among these radiolarians, they identified *Bientactinosphaera egindyensis* (Nazarov) and *B. aitpaiensis* (Nazarov), which are typical of the Frasnian Stage of the northern Mugodzhary. In addition, they distinguished specific forms *B. guangxiensis* (Li et Wang) and *Cyclocarpus tubiformis* Li et Wang (Li and Wang, 1991).

Holdsworth and Jones (1980) suggested the first radiolarian biozonation for the Upper Devonian–Permian basin of the Yukon River area in eastern Alaska. Using regularities in the evolution of *Albaillellaria* forms during the indicated age interval, they recognized several radiolarian assemblages supplemented with their very brief characteristics. In their work, Frasnian radiolarians were integrated into one *Pre-Holoeciscus* zonal assemblage (Table 1).

A unified biostratigraphic scale for Paleozoic radiolarian was elaborated by Nazarov (1975, 1984, 1988) who based it on a detailed analysis of time-and-space distribution of all Paleozoic radiolarians known at that time. The scale was later refined in a series of works by Nazarov and Ormiston (1983, 1985, 1986, 1990, 1993). In accordance with their scheme, the Upper Devonian is characterized by two radiolarian assemblages: *Bientactinosphaera egindyensis–Polyenactinia circumretia* typical of the Frasnian Stage and *Tetrentactinia barysphaera–Ceratoikiscum famenium* for the Famennian deposits (Table 1).

A revision of the Frasnian radiolarians of the Timan–Pechora basin in the northern Mugodzhary, the Northern Urals and Western Australia allowed to establish three radiocarbon zones within the Frasnian Stage: *Bientactinosphaera egindyensis–Polyentactinia circumretia* in the upper Frasnian, *Moskovistella allbororum–Ceratoikiscum ukhtenses* in the middle Frasnian, and *Helenifore gogoense–Retisphaera concinna* in the lower Frasnian (Afanas'eva and Aitchison, 1999).

RADIOLARIAN ZONES

Helenifore gogoense–Retisphaera concinna Zone

Aitchison (1993) and Won (1997a, 1997b) published the detailed description of the diverse radiolarian assemblage including 130 species and subspecies, which occur in carbonate concretions from the lower part of the Gogo Formation (the lower Frasnian Substage) of the Canning basin in Western Australia. Correlating this radiolarian assemblage with the standard conodont scale (Lower to Middle *Mesotaxis asymmet-*

Table 1. Radiolarian Frasnian zones and middle Frasnian (Domanik) subzones of the Upper Devonian

System	Series	Stage	Substage	Standard Conodont Zonation	Holdsworth and Jones, 1980; Eastern Alaska	Nazarov, 1975, 1984, 1988; Nazarov and Ormiston, 1985, 1993; Kazakhstan, northern Mugodzhary		Afanas'eva, 1997; Afanas'eva and Aitchison, 1999; Timan–Pechora basin in Russia and Canning Basin in Western Australia		
Devonian	Upper	Frasnian	Upper	*linguiformis*	*Pre-Holloeciscus*	Egindy Formation	*Bientactinosphaera egindyensis–Polyentactinia circumretia*	*Bientactinosphaera egindyensis–Polyentactinia circumretia*	Livny Formation	
				Late *rhenana*					Evlanovo Formation	
				Early *rhenana*					Sirachoi Formation	
			Middle	*jamieae*					Vetlosyan Formation	
				Late *hassi*				*Moskovistella allbororum–Ceratoikiscum ukhtensis*	Domanik Formation	Rdm-3
				Early *hassi*						Rdm-2
				punctata						Rdm-1
			Lower	*transitans*				*Helenifore gogoense–Retisphaera concinna*	Ust'-Yarega Formation	
				Late *falsilovalis*					Timan Formation	
				Early *falsilovalis*						

ricus Zone), they distinguished the radiolarian *Helenifore gogoense–Retisphaera concinna* Zone characterizing the lower Frasnian deposits (Tables 1 and 2).

Dominant species of the early Frasnian radiolarian assemblage, which are also distributed in younger deposits of the Timan–Pechora basin and northern Mugodzhary area, are *Entactinia aperticuva* Aitchison, *Palaeoscenidium robustum* Aitchison, and *Helioentactinia stellaepolus* Aitchison (Table 2; Plate, Fig. 27). The described early Frasnian radiolarian assemblage is free of species characteristic of either the middle, or the late Frasnian radiolarian zones, whereas the Middle Devonian species *Entactinia hystricuosa* Aitchison; *Bientactinosphaera aculeatissima* (Aitchison), *Helenifore laticlavium* Nazarov et Ormiston are well represented in this assemblage.

The early Frasnian assemblage of radiolarians from the Gogo Formation is remarkable owing to abundant representatives (33 species) of echinate radiolarians from the Ceratoikiscidae and Palaeoscenidiidae families. Most typical representatives of the assemblage, which are unknown among radiolarians from younger deposits of the northern Mugodzhary area and Timan–Pechora basin thus being typical only of the lower Frasnian deposits, are *Paleotripus gogoense* Aitchison, *Ceratoikiscum torale* Aitchison, *C. spiculatum* Aitchison, *Palaeoscenidium venustum* Aitchison, *Secuicollacta araneam* Aitchison, and *Entactinia proceraspina* Aitchison (Table 2; Plate, figs. 21, 23–25, 28, 29).

Radiolarian species typical of the lower Frasnian are *Ceratoikiscum echinatum* Aitchison, *Helenifore gogoense* Aitchison, *Entactinia hystricuosa* Aitchison, and *Retisphaera concinna* (Aitchison) (Plate, figs. 22, 26, 30, 31).

An impoverished early Frasnian radiolarian assemblage (nine species, six genera) was also established in the Ust'-Yarega Formation of the southern part of the Timan–Pechora province (Afanas'eva, 2000).

Moskovistella allbororum–Ceratoikiscum ukhtensis Zone

The study of radiolarians from the complete section of the Domanik Formation in the boreholes and exposures of the Ukhta region in the Timan–Pechora paleobasin allowed the author to identify a well-preserved radiolarian assemblage (Afanas'eva, 1994, 1996, 1997, 1998, 1999, 2000; Afanas'eva and Mikhailova, 1994, 1995a, b; 1997, 1998 (in press); Afanas'eva, 1997, 1998; Afanas'eva and Mikhailova, 1994, 1995). A detailed analysis of the radiolarians of the Domanik Formation, containing 127 species of 35 genera, and the correlation of the established radiolarian assemblage with the standard zones of ammonoids (*Ponticeras domanicense–Nordiceras timanicum*) and conodonts (*Palmatolepis punctata–Palmatolepis rhenana*) (Menner *et al.*, 1992; Becker *et al.*, 1995; House *et al.*, in press) allows to attribute the zone *Moskovistella allbororum–Ceratoikiscum ukhtensis*, established earlier (Afanas'eva 1997a, b), to the middle Frasnian (Tables 1 and 2).

Table 2. Characteristic radiolarian species of the Frasnian Stage

Radiolarian species	Frasnian Stage		
	Lower	Middle	Upper
	Helenifore gogoense–Retisphaera concinna	*Moskovistella allborорum–Ceratoikiscum ukhtensis*	*Bientactinosphaera egindyensis–Polyentactinia circumretia*
Ceratoikiscum echinatum Aitchison			
Ceratoikiscum spiculatum Aitchison			
Ceratoikiscum torale Aitchison			
Entactinia hystricuosa Aitchison			
Entactinia proceraspina Aitchison			
Helenifore gogoense Aitchison			
Paleotripus gogoense Aitchison			
Retisphaera concinna (Aitchison)			
Secuicollacta araneam Aitchison			
Helioentactinia stellaepolus Aitchison			
Ornatoentactinia solita Afanasieva			
Spongentactinella olafi Afanasieva			
Moskovistella allborорum Afanasieva			
Moskovistella victorialis Afanasieva			
Radiobisphaera menneri Afanasieva			
Bientactinosphaera morozovi Afanasieva			
Borissella bykovae Afanasieva			
Ceratoikiscum ukhtensis Afanasieva			
Moskovistella khaini Afanasieva			
Nazarovites bioculus Afanasieva			
Polyentactinia zhamoidae Afanasieva			
Astroentactinia crassata Nazarov			
Astroentactinia paronae (Hinde)			
Bientactinosphaera aitpaiensis (Nazarov)			
Bientactinosphaera egindyensis (Nazarov)			
Bientactinosphaera guangxiensis (Li et Wang)			
Polyentactinia kissistekensis (Nazarov)			
Polyentactinia circumretia Nazarov et Ormiston			
Astroentactinia stellata Nazarov			
Cyclocarpus tubiformis Li et Wang			

The prevalent species of the middle Frasnian radiolarian assemblage are *Bientactinosphaera grandis* (Nazarov), *B. variacanthina* (Foreman), *B. symphypora* (Foreman), *Astroentactinia paronae* (Hinde), *A. biaciculata* Nazarov, *Spongentactinella veles* (Foreman), *Polyentactinia kossistekensis* Nazarov, *Palaeoscenidium cladophorum* Deflandre, *Ceratoikiscum delicatum* Cheng, *C. spinosum* Cheng, *C. planistellare* Foreman, *C. bujugum* Foreman, *Palacantholithus stellatus* Deflandre.

The most typical representatives of the assemblage of the middle Frasnian deposits are: *Moskovistella victorialis* Afanasieva, *M. khaini* Afanasieva, *Bientactinosphaera morozovi* Afanasieva, sp. nov., *Polyentactinia zhamoidai* Afanasieva, sp. nov.; *Borisella bykovae* Afanasieva, *Ornatoentactinia solita* Afanasieva, *Nazarovites bioculus* Afanasieva (Plate, figs. 11–13, 15–17, 20).

The most typical species of the middle Frasnian radiolarian assemblage are *Moskovistella allborорum* Afanasieva, *Radiobisphaera menneri* Afanasieva, sp. nov., *Spongentactinella olafi* Afanasieva, sp. nov., and *Ceratoikiscum ukhtensis* Afanasieva (Plate, figs. 10, 14, 18, 19).

The detailed analysis of radiolarians from the Domanik Formation allowed us to subdivide the radiolarian *Moskovistella allbororum–Ceratoikiscum ukhtensis* Zone into three subzones (lower Rdm–1, middle Rdm–2, and upper Rdm–3), the radiolarian assemblages of which are essentially different with respect to their taxonomic composition and species abundance (Afanas'eva, 1997; Afanas'eva and Mikhailova, in press).

Bientactinosphaera egindyensis–Polyentactinia circumretia Zone

Nazarov who distinguished the biostratigraphic *Bientactinosphaera egindyensis–Polyentactinia circumretia* Zone substantiated this subdivision using the radiolarian assemblage from the Egindy Formation, the Aitpaika River locality of the northern Mugodzhary (Nazarov, 1973; 1975; 1988).

In the lower part of the Egindy Formation section, siliceous shales and breccias concordantly overlie detrital rocks of the Givetian Stage, and the late Givetian age of the lowermost Egindy beds was not ruled out (Nazarov, 1975). In the middle part of the section, cherty rocks are intercalated with well-outlined lenses of carbonate concretions set in the dark gray siliceous matrix bearing *Palmatolepis subrecta* Miller et Youngg. and poorly preserved radiolarians. In contrast, the carbonate concretions proper bear an assemblage of abundant and diverse radiolarians (more than 50 species of 15 genera) associated with conodonts species *Palmatolepis punctata* Hinde, *P. hassi* Mueller, *P. subrecta* Miller et Youngg., and *P. foliacea* Hinde (Nazarov, 1975; 1988; Nazarov and Ormiston, 1993). These findings indicate that the host rocks accumulated at the end of the middle and during the late Frasnian (the conodont *Palmatolepis rhenana–Palmatolepis linguiformis* zone). The uppermost part of the Egindy Formation section at the Aitpaika River is correlated, on the basis of characteristic spore assemblage, with the lower Famennian Elets Horizon of the Russian platform (Nazarov, 1975).

Radiolarians most widespread in the assemblage under consideration are *Bientactinosphaera grandis* (Nazarov), *B. variacanthina* (Foreman), and *Spongentactinella veles* (Foreman), *Palaeoscenidium cladophorum* Deflandre, *Ceratoikiscum planistellare* Foreman. The corresponding time period is also marked by appearance of numerous *Polyentactinia kossistekensis* Nazarov, *Astroentactinia crassata* Nazarov, *A. paronae* (Hinde), *Bientactinosphaera aitpaiensis* (Nazarov), and *Bientactinosphaera guangxiensis* (Li et Wang) (Plate, figs. 2, 4–6, 9).

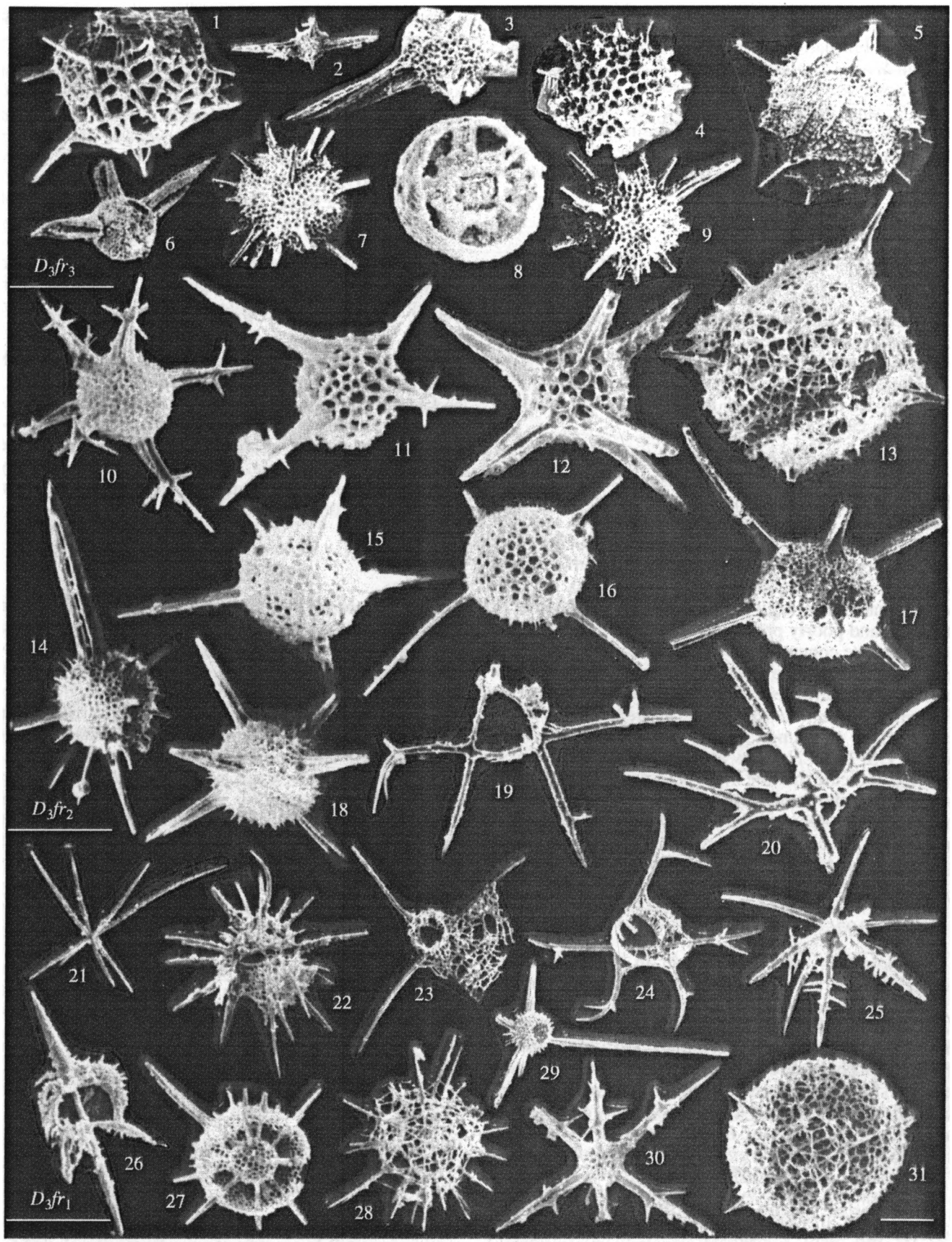
Radiolarian species typical of the upper Frasnian assemblage are *Polyentactinia circumretia* Nazarov et Ormiston, *Bientactinosphaera egindyensis* (Nazarov), *Astroentactinia stellata* Nazarov, and specific *Cyclocarpus tubiformis* Li et Wang (Table 2; Plate, figs. 1, 3, 7, 8).

The upper Frasnian radiolarian assemblage of *Moskovistella allbororum* Afanasieva (*Entactinia addivita?* in determination by Nazarov, 1988), *Entactinia* cf. *dissora* Nazarov, *Bientactinosphaera* cf. *grandis* (Nazarov), *B. aff. cancellicula* (Foreman), *Polyentactinia* sp., and *Astroentactinia* sp. was recovered by Nazarov from limestone interbeds in the sequence of clayey–cherty shales and siltstones of the Evtropiny Formation at the Evtropiny Noski site (the Malopechorskii allochthon in the Un'ya River basin of the northern Urals), where these radiolarians associate with conodonts of the *Palmatolepis gigas* Zone (Nazarov, 1988).

Another characteristic radiolarian assemblage with abundant *Bientactinosphaera egindyensis* (Nazarov) and rather numerous *Polyentactinia circumretia* Nazarov et Ormiston was distinguished in the upper Frasnian Vetlosyan Formation of the southern area of the Timan–Pechora province, where this formation directly overlies the Domanik Formation of the middle Frasnian (Afanas'eva, 2000).

CONCLUSIONS

Our comparison of Frasnian radiolarians from the studied localities and other regions of the world showed, on the one hand, that the typical upper Frasnian species *Bientactinosphaera aitpaiensis* (Nazarov), *B. guangxiensis* (Li et Wang) and *Polyentactinia circumretia* Nazarov et Ormiston are present in the middle Frasnian assemblage only as single specimens discovered from the uppermost beds of the section (Table 2; Plate, figs. 1, 2, 6), where *Cyclocarpus tubiformis* Li et Wang and *Astroentactinia stellata* Nazarov are completely absent (Table 2; Plate, figs. 7, 8). On the other hand, deposits of the Domanik Formation (the middle Frasnian) yield abundant species *Spongentactinella windjanensis* Nazarov, *Ornatoentactinia solita* Afanasieva, *O. spartaki* Afanasieva (determined by Nazarov as *Entactinosphaera* cf. *cancellicula* Foreman) and *Ceratoikiscum stellatum* Aitchison, which first appear at the end of the Middle Devonian and have been detected by Nazarov in the lower part of the Gogo Formation in Western Australia (Nazarov *et al.*, 1982). These radiolarian species are absent not only in the Famennian, but even in the upper Frasnian. Moreover, the studied radiolarian assemblage from the middle Frasnian Domanik Formation has many species in common with the radiolarian assemblage from the upper part of the Gogo Formation in Western Australia (Nazarov and Ormiston, 1983; Aitchison, 1993). These are *Bientactinosphaera echinata*, *Radiobisphaera assidera* (Nazarov), *Ceratoikiscum delicatum* Cheng, *C. bujugum* Foreman, *Palaeoscenidium cladophorum* Deflandre, *Spongentactinella* sp. 1 (= *S. olafi* Afanasieva, sp. nov.), *Palaeoscenidium delicatum* Aitchi-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son, *P. phalangium* Aitchison, and several other species.

It should be noted that the radiolarians from the Egindy Formation of the upper Frasnian Substage, the Aitpaika River locality of the northern Mugodzhary, are most similar, in their generic and species composition, and also in size range, with radiolarians described by Foreman (1963), the assemblage of which was recovered from the Upper Devonian Huron Member of the Ohio Shales of North America (Nazarov, 1975, 1988). On the other hand, the radiolarians from the lower Frasnian deposits of the Gogo Formation in the Canning basin of Western Australia resemble more closely the older radiolarians of the Middle Devonian. Finally, the radiolarian assemblage from the middle Frasnian Domanik Formation of the Timan–Pechora province in Russia has several species in common with both the early and late Frasnian radiolarian assemblages thus representing a connecting link in the evolutionary lineage of Frasnian radiolarian assemblages.

Thus, the revision of radiolarians recovered in different regions from various Frasnian subdivisions, namely (1) from the lower Frasnian part of the Gogo Formation in the Canning basin of Western Australia, (2) from the Domanik Formation of the middle Frasnian in the Timan–Pechora paleobasin, and (3) from the upper Frasnian deposits corresponding to the Egindy Formation of the northern Mugodzhary, the Evtropiny Formation of northern Urals and the Vetlosyan Formation of the southern Timan–Pechora province, allowed us to establish three radiolarian zones within the Frasnian Stage: *Bientactinosphaera egindyensis–Polyenactinia circumretia* Zone of the upper Frasnian, *Moskovistella allbororum- -Ceratoikiscum ukhtensis* Zone of the middle Frasnian, and *Helenifore gogoense–Retisphaera concinna* Zone of the lower Frasnian (Tables 1 and 2).

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Plate. Radiolarians of the Frasnian Stage

(1–9) Radiolarian assemblage of the *Bientactinosphaera egindyensis–Polyentactinia circumretia* Zone of the upper Frasnian, (1–5, 7, 9) Kazakhstan, northern Mugodzhary, Aitpaika River, sample B45/1–5 (from Nazarov's archive); (6, 8) China, east-southeastern Guangxi province, Liukiang Formation (Li and Wang, 1991, Pl. I, 2, 7): (1) *Polyentactinia circumretia* Nazarov, GIN no. 4046/95 (scale bar 60 μm); (2) *Bientactinosphaera aitpaiensis* (Nazarov), GIN no. 4046/106 (scale bar 150 μm); (3) *B. egindyensis* (Nazarov), GIN no. 4046/98 (scale bar 43 μm); (4) *Astroentactinia crassata* Nazarov, GIN no. 4046/109 (scale bar 60 μm); (5) *Polyentactinia kossistekensis* Nazarov, Gin no 4046/97 (scale bar 67 μm); (6) *Bientactinosphera guangxiensis* (Li et Wang), E–F–19 (scale bar 125 μm; (7) *Astroentactinia stellata* Nazarov, GIN no. 4046/119 (scale bar 67 μm); (8) *Cyclocarpus tubiformis* Li et Wang, E-F-13 (scale bar 58 μm); (9) *Astroentactinia paronae* (Hinde), GIN no. 4046/111 (scale bar 110 μm); (10–20) Radiolarian assemblage of the *Moskovistella allbororum–Ceratoikiscum ukhtensis* Zone of the middle Frasnian Russia, Timan–Pechora basin, the Lyaiyol' River, Exposure 1904: (10, 11, 16, 19, 20) borehole Shuda-Yag-1003, Sample 6, (12, 14) Sample 68 (int. 73.0–73.3 m), (13) Sample 29 (int. 105.0–106.0 m), (17) Sample 8 (int. 120.9–124.9 m); borehole Ukhtinskaya-3B, (15) Sample 114 (int. 104.2–104.7 m); Ukhta River, Site 4, (18) Sample 29; (10) *Moskovistella allbororum* Afanasieva, FF-P001/033-09512 (scale bar 56 μm); (11) *M. victorialis* Afanasieva, FF-P001/032-09628 (scale bar 50 μm); (12) *M. khaini* Afanasieva, FF-P001/041-04727 (scale bar 37 μm); (13) *Polyentactinia zhamoidai* Afanasieva, FF-P001/011-04722 (scale bar 50 μm); (14) *Radiosphaera menneri* Afanasieva, sp. nov., FF-P001/014-04714, holotype (scale bar 50 μm); (15) *Bientactinosphaera morozovi* Afanasieva, FF-P001/116-09212 (scale bar 33 μm); (16) *Borisella bykovae* Afanasieva, FF-P001/037-09537 (scale bar 50 μm); (17) *Spongentactinella olafi* Afanasieva, FF-P001/056-04125 (scale bar 100 μm); (18) *Ornatoentactinia solita* Afanasieva, FF-P001/043-13126 (scale bar 63 μm); (19) *Ceratoikiscum ukhtensis* Afanasieva, FF-P001/106-09835 (scale bar 67 μm); (20) *Nazarovites bioculus* Afanasieva, FF-P001/092-09834 (scale bar 56 μm); (21–31) Radiolarian assemblage of the lower Frasnian *Helenifore gogoense–Retisphaera concinna* Zone, Western Australia, Canning basin, Gogo Formation (18°25.8′ S, 125°54.3′ E): (21) *Paleotripus gogoense* Aitchison, no. GSWA–F43981 (scale bar 86 μm); (22) *Ceratoikiscum echinatum* Afanasieva, no. GSWA-F44019 (scale bar 71 μm); (23) *C. torale* Aitchison, no. GSWA–F44022 (scale bar 100 μm); (24) *C. spiculatum* Aitchison, no. GSWA–F43991 (scale bar 115 μm); (25) *Palaeoscenidium venustum* Aitchison, no. GSWA–F4365 (scale bar 58 μm); (26) *Helenifore gogoense* Aitchison, no. GSWA–F44025 (scale bar 77 μm); (27) *Helioentactinia stellaepolus* Aitchison, no. GSWA–F44081 (scale bar 71 μm); (28) *Secuicollacta araneam* Aitchison, no. GSWA–F44079 (scale bar 48 μm); (29) *Entactinia proceraspina* Aitchison, no. GSWA–F44069 (scale bar 150 μm); (30) *E. hystricuosa* Aitchison, no. GSWA–F44063 (scale bar 63 μm); (31) *Retisphaera concinna* (Aitchison); no. GSWA-F44057 (scale bar 67 μm).

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First Finds of Permian Ammonoids in the Kotel'nyi Island

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Abstract—First ammonoid remains are found in the Lower Permian Munugudzhak Horizon, the northwestern coast of the Kotel'nyi Island (New Siberian Islands). They are used to define more precisely the age of host deposits and to clarify their paleontological characteristics. Stratigraphic distribution of the distinguished ammonoid taxa and similar forms in the Permian sections of the Urals and Verkhoyansk region is analyzed. New paleontological data substantiate the Sakmarian Stage presence in the Permian System of the Kotel'nyi Island. Two ammonoid species *Preshumardites bogoslovskyi* Andrianov and *Tabantalites etchiensis* Andrianov are described.

Key words: ammonoids, Permian System, Sakmarian Stage, New Siberian Islands, Kotel'nyi Island.

INTRODUCTION

Ammonoids represent a faunal group rarely occurring in the Permian deposits of northeastern Asia. Most of the known localities of Permian ammonoids are situated in the northern and western parts of the Verkhoyansk region, but these fossils are scarce in the Okhotsk, Kolyma, and Omolon median masses (Andrianov, 1985). Although the Permian ammonoids are less widespread in northeastern Asia than bivalves and brachiopods, their stratigraphic potential is very important for correlation of regional stratigraphic schemes with the general scale of the Permian System and for the stage subdivision of host deposits (Ustritskii, 1971; *Osnovnye cherty...*, 1984; Andrianov, 1985).

In the New Siberian Islands, Permian ammonoids have been unknown until now, and the age substantiation of Permian strata was based on distribution of foraminifers and brachiopods in the sections (Vol'nov *et al.*, 1974; *Resheniya...*, 1978; *Osnovnye cherty...*, 1984). Ammonoids collected from the Lower Permian deposits of the Kotel'nyi Island determine more precisely the strata age and enable recognition of the Sakmarian Stage in the local Permian section.

STRATIGRAPHIC POSITION OF FOUND AMMONOIDS

In the Kotel'nyi Island, Permian deposits were recognized at the northwestern coast of the island and in its central part, where they are exposed in the Balyktakh River middle courses (Vol'nov *et al.*, 1974). The deposits correspond to the terrigenous sequence of predominant shales and siltstones intercalated with sandstone interlayers and limestone lenses. The most complete section of these rocks was described at the northwestern coast of the island (Fig. 1) to the west of the polar station "Kotel'nyi" (Vol'nov *et al.*, 1974).

Permian deposits, the lower boundary of which has not been established, are of a distinct rhythmical structure. They are divided into two members (Fig. 2).

The basal portion (35 m) of the lower member is composed of unconsolidated clay grading upward into shales and clayey siltstones. The upper half of the member consists of shale and siltstone beds intercalated with interbeds of feldspar–quartz and polymictic sandstones, and also with limestone lenses. Limestones located in the middle of the member yield brachiopods *Jakutoproductus verchoyanicus* (Fredericks). Siltstone and sandstone beds bear plant detritus. The member is 100 m thick.

The upper member consists of shales intercalated with siltstone and fine-grained sandstone interbeds. In the lower interval of the member, foraminifers *Nodosaria bella* Gerke, *N.* ex gr. *bradyi* (Spandel), and *N.* ex gr. *ustritskyi* Sossipatrova coexist with brachiopods *Anidanthus rugoses* Licharew. Foraminifers *Nodosaria* cf. *crassiformis* Igonin and *Frondicularia* aff. *pseudotriangularis* Gerke are characteristic of the upper part of the member, where they associate with brachiopods *Achunoproductus achunovensis* (Stepanov) and *Spiriferella lita* Fredericks. Sandstones and siltstones again contain the plant detritus. The upper member is 100 m thick.

Relationships between Permian and overlying Triassic deposits are unclear, and it is assumed that these systems are separated by a hiatus spanning the uppermost Permian horizons. The basal interval of the Lower Triassic, conditionally attributed to the Induan Stage, consists of alternating greenish gray thin-laminated and black gypsum-bearing shale up to 30 m thick, which

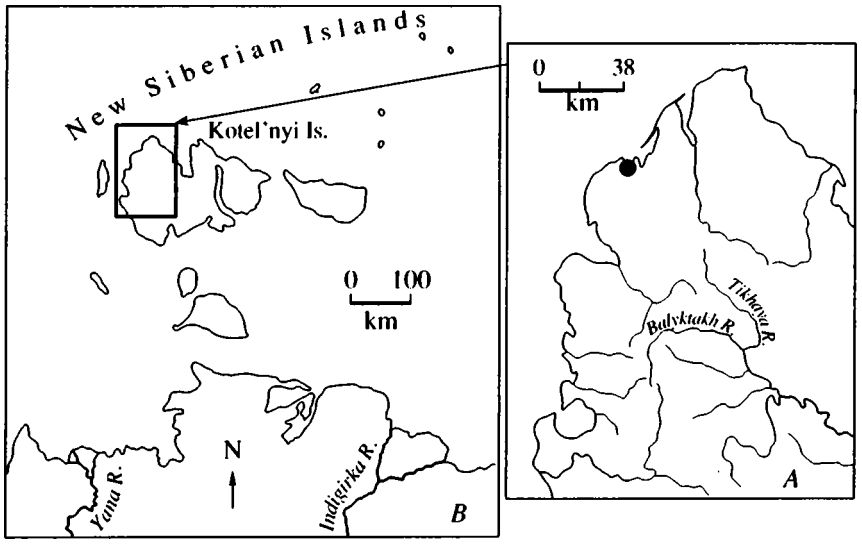

Fig. 1. Geographic position of the study area (rectangle) and sampling sites (black dots) of Permian ammonoids in the northwestern coast of the Kotel'nyi Island.

enclose bun-shaped siderite concretions (Preobrazhenskaya *et al.*, 1975; Egorov *et al.*, 1987).

Owing to the presence of characteristic brachiopod species *Jakutoproductus verchoyanicus* (Fred.), the lower member is correlated with the Munugudzhak Horizon distinguished in the regional Permian stratigraphic scheme of the Kolyma–Omolon province (Vol'nov *et al.*, 1974; *Resheniya...*, 1978). As it was accepted (*Osnovnye cherty...*, 1984), this horizon spans the summary interval of the Asselian and Sakmarian stages coupled with the lower Artinskian Substage. The upper member yields foraminifers widespread in the Dzhigdala and Omolon horizons of the Kolyma–Omolon province, which include the age analogues of the upper Artinskian Substage and Kungurian Stage of the Lower Permian, and also of the Ufimian Stage of the Upper Permian.

Thus, the brachiopod and foraminiferal fauna from Permian deposits of the Kotel'nyi Island was previously used to distinguish here the upper and lower series of the system, which were divided into the Munugudzhak, Dzhigdala, and Omolon horizons.

In 1984, I found for the first time the ammonoid species *Preshumardites bogoslovskyi* Andrianov and *Tabantalites etchiensis* Andrianov in the middle part of the Munugudzhak Horizon exposed at the northwestern coast of the Kotel'nyi Island. Both species were recovered from one stratigraphic level (50 m above the section base) in small pyritized concretions, which are set in the bed of firm coarse-grained siltstone. These finds better elucidating the stage interval of host deposits can be used a basis for the interregional correlation.

The collection of recovered fossils is stored under no. 988 at the paleontological department of the Central Siberian Geological Museum (Joint Institute of Geol-

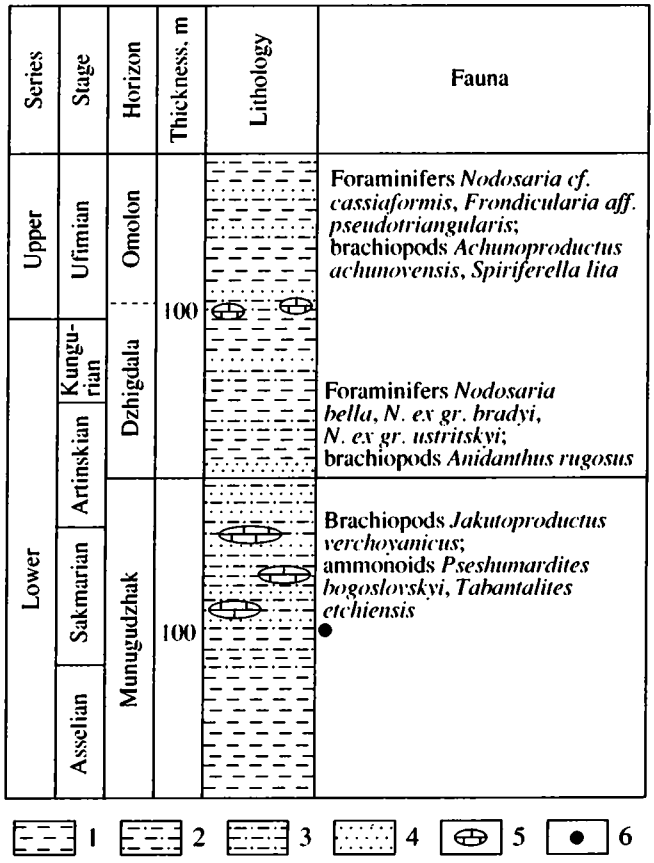

Fig. 2. Lithostratigraphy of Permian deposits in the northwestern coast of the Kotel'nyi Island: (1) shale; (2) clayey siltstone; (3) siltstone; (4) sandstone; (5) carbonate nodules and lenses; (6) levels of sampled ammonoids; distribution of brachiopods and foraminifers is shown on the basis of published data (*Resheniya...*, 1978).

ogy, Geophysics, and Mineralogy, Siberian Division, Russian Academy of Sciences, Novosibirsk). In ammonoids description presented below, I use the following abbreviations: (D) shell diameter; (W) width of the last whorl; (H) height of the last whorl; (DU) diameter of umbilicus.

BIOSTRATIGRAPHIC ANALYSIS AND AGE SUBSTANTIATION

Ammonoid species from the middle part of the Munugudzhak Horizon of the Kotel'nyi Island are counterparts of those originally described by Andrianov (1985), who discovered them in the Lower Permian of the northern and western Verkhoyansk region. *Preshumardites bogoslovskyi* Andrianov is widespread in the lower part of the Tuora-Sis Formation of the Kharaulakh Range and in the Endybal-Echii Formation of the Dulgalakh River basin, where it coexists with ammonoids of the genus *Metapronorites*. In opinion of Andrianov, *Preshumardites bogoslovskyi* Andr. is very similar to *P. sakmarae* Ruzhencev from the Sterlitamak Horizon of the Urals (Ruzhentsev, 1938; p. 283; Plate VI, figs. 22 and 23; Plate VII, figs. 5–8), but differs from the latter owing to the less developed cusps at the external lateral lobe, peculiar shape of umbilical lobe, and different orientation of cusp in the latter relative to the umbilical margin. Single specimen of the described *Tabantalites etchiensis* Andrianov was collected in the Lena River lower courses from the banded siltstone bed situated in the lower part of the Tuora-Sis Formation. At this level, it coexists with two other ammonoids *Bulunites juferevi* Andrianov and *Juresanites maximovae* Andrianov.

The complete ammonoid assemblage from the lower part of the Tuora-Sis Formation consists of the following species collected at different localities of the Kharaulakh Ridge: *Metapronorites vladimiri* Andrianov, *Neopronorites* sp., *Agathiceras verchoyanicum* Andrianov, *Bulunites mezhvilki* Andrianov, *B. juferevi* Andr., *Preshumardites bogoslovskyi* Andr., *Tabantalites etchiensis* Andr., *Menneroceras menneri* Andrianov, and *Juresanites maximovae* Andr. Another assemblage of comparable composition is known from the Khorokyt Formation and coeval strata of the western Verkhoyansk region, where it consists of *Metapronorites* sp., *Neopronorites* aff. *milleri* Ruzhencev, *Somoholites* sp., *Bulunites* aff. *mezhvilki* Andr., and *Paragastrioceras* sp. These ammonoids were originally dated back to the Asselian–Sakmarian time interval (Andrianov, 1985). As it was established afterward, the partial correlation of the Tuora-Sis Formation with the Asselian Stage is misleading, because species *Juresanites maximovae* Andr. and *Menneroceras menneri* Andr. belong most likely to the genus *Eoasianites* being similar to its later (Sakmarian) forms (Kotlyar *et al.*, 1987).

Ammonoids *Preshumardites bogoslovskyi* Andr. and *Tabantalites etchiensis* Andr., occurring at one level in the Kotel'nyi Island, are unknown as coexisting in the Kharaulakh Ridge. From this standpoint, it seems doubtful to suspect that the Tuora-Sis Formation, the lower part of which should be attributed to the Sakmarian Stage, includes chronoequivalents of the Asselian Stage.

The last conclusion is favored by occurrence of *Preshumardites* forms only in ammonoid assemblages exclusively typical of the Sakmarian Stage (Ruzhentsev, 1951). In particular, *Preshumardites sakmarae* Ruzh., which was considered by Andrianov as most similar to *P. bogoslovskyi* Andr. from the Verkhoyansk region, is the guide taxon of the Sakmarian Stage (Ruzhentsev, 1950, 1951, 1952). In the type area of southern Urals at the Sakmara River, the stratigraphic range of *P. sakmarae* Ruzh. spans the upper part of the Tastuba Horizon and the entire Sterlitamak Horizon. Ammonoids from this stratigraphic interval represent an assemblage of the *Preshumardites sakmarae–Synartinskia principalis* Zone (*Osnovnye cherty...*, 1984).

The genus *Tabantalites* existed in the late Asselian–early Sakmarian time. *T. bifurcatus* Ruzhencev, the type species of the genus, is characteristic of the upper Asselian Substage and of the lower Tastuba beds of the Sakmarian Stage in the Aktyuba district of the southern Urals (Ruzhentsev, 1952), being most abundant exactly in the Tastuba Horizon. Outside the Urals, *T. bifurcatus* Ruzh. was identified in the upper part of the Jungle Creek Formation, the Peel River basin of northern Canada (Nassichuk, 1971), where it associates with ammonoid species *Prothalassoceras bostocki* Nassichuk, *Properrinites furnishi* Nassichuk, *? Uraloceras* sp., *Svetlanoceras* cf. *S. irwinense* (Teichert et Glenister), *Eoasianites* aff. *E. trapezoidales* Maximova, *Somoholites* cf. *S. beluensis* (Haniel), and *Medlicottia* sp. As the genus *Medlicottia* do not occur in pre-Sakmarian deposits, age of this fauna is defined as corresponding to the early Sakmarian (Tastuba) time (Nassichuk, 1971, 1995).

As compared to *T. bifurcatus* Ruzh., Siberian representatives of the genus *Tabantalites* have wider whorls, and the stage of involute shell appears earlier in their ontogeny. This may indicates that *Tabantalites etchiensis* Andr. characterizes a higher evolutionary stage, and, consequently, its host deposits may be younger.

In general, ammonoids found in the middle part of the Munugudzhak Horizon of the Kotel'nyi Island suggest that their host rocks correspond to the Sakmarian Stage and can be correlated with the lower beds of the Tuora-Sis Formation of the Kharaulakh Ridge, and also with the Khorokyt Formation and basal strata of the Endybal-Echii Formation of the western Verkhoyansk region.

DESCRIPTION OF AMMONOIDS

Family Somoholitidae Ruzhencev, 1938

Genus *Preshumardites* Plummer et Scott, 1937

Preshumardites bogoslovskyi Andrianov, 1985

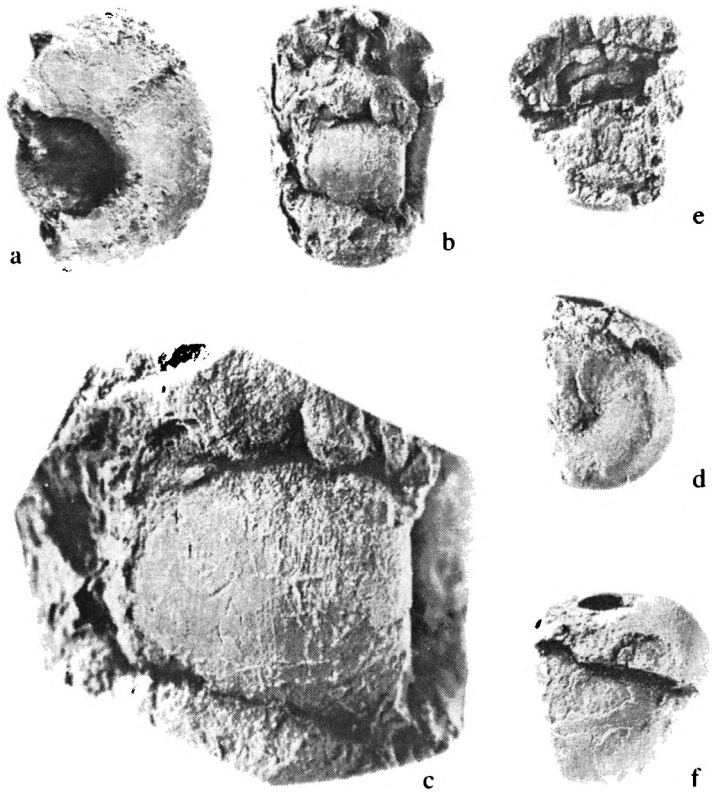

Plate. Ammonoids from Permian deposits of the Kotel'nyi Island.
(a–c) *Preshumardites bogoslovskyi* Andrianov. Specimen no. 1/988: (a) lateral side, ×1; (b) apertural side, ×1; (c) view of inner whorl, ×3; middle part of the Munugudzhak Horizon, Sakmarian Stage.
(d–f) *Tabantalites etchiensis* Andrianov. Specimen no. 2/988: (d) lateral side, ×3; (e) apertural side, ×3; (f) ventral side, ×3; the same locality and age.

Plate, figs. a, b, c; Fig. 3, drawings a and b

Preshumardites bogoslovskyi: Andrianov, 1985; p. 123; Plate IV, figs. 1 and 2; Plate V, fig. 1.

Holotype: no. 55/562; Andrianov, 1985, Plate IV, figs. 1 and 2; Yakut Branch Museum, Siberian Division, Russian Academy of Sciences; northern Verkhoyansk region, Kharaulakh Ridge; left side of the Lena River southward of the Chekurovka Settlement; Tuora-Sis Formation, Sakmarian Stage.

Shape. Inner whorls are missing. When the shell diameter is 16 mm, the whorl cross sections are oval. The ventral side is gently convex, merged with more convex lateral sides. When its diameter is 35 mm, the shell of the pachycone type is swollen, semi-involute, and displaying the moderately growing height of whorls. Ventral and lateral sides form a single convex surface. The umbilical shoulder is distinct and rounded. The umbilical wall is fairly high and slightly convex. Umbilicus is moderately wide, deep, and step-wise in configuration. The living chamber is not preserved.

Specimen no.	D	H	W	DU	H/D	W/D	DU/D
1/988	35	13	27	13	37	77	37

Sculpturing. Ventral and lateral sides of the shell are decorated with thin longitudinal striae. The internal mold is smooth. When the shell diameter is 14 mm, there is clearly seen a constriction that forms shallow sinuses on lateral sides and a wide prominent embossing on the ventral side.

Lobe line. The ventral lobe is subdivided by a rather high and wide siphonal saddle into two narrow cusped branches widening in the middle (Fig. 3a). The first lateral lobe is compressed at the top and widens downward forming rounded projections on sides and a long wedge at the base (Figs. 3a and 3b). At the early growing stages, the lateral projections are more distinct. The umbilical lobe is wide, and its projection is situated close to the umbilical shoulder.

Comparison. Species *P. bogoslovskyi* is different from the most similar *P. gorbunovi* (Andrianov, 1985; p. 125; Plate VI, fig. 2), because its first lateral lobe is symmetrical, and the umbilical lobe is wide. As compared to *P. sakmarae* (Ruzhentsev, 1938; p. 283; Plate VI, figs. 22 and 23; Plate VII, figs. 5–8), the described species has the narrower shell with the more convex ventral side and high medial saddle.

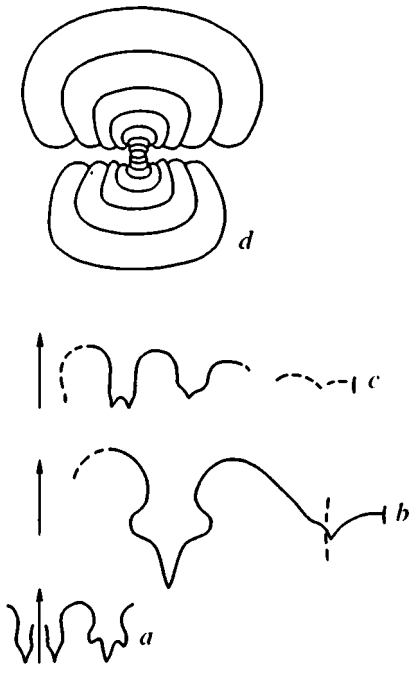

Fig. 3. Lobe lines and cross section of ammonoid shells. *Preshumardites bogoslovskyi* Andrianov. Specimen no. 1/988: (*a*) W = 14 mm, ×2.4; (*b*) W = 22 mm, ×2.8, H = 13 mm. *Tabantalites etchiensis* Andrianov. Specimen no. 2/988: (*c*) W = 5.4 mm, H = 3.9 mm, ×16; (*d*) shell cross section of this specimen (sampling site and age as in the Plate).

Distribution: Sakmarian Stage, Tuora-Sis Formation of the Kharaulakh Ridge, Endybal-Echii Formation of the western Verkhoyansk region, and Munugudzhak Horizon of the Kotel'nyi Island.

Material: one specimen from the northwestern coast of the Kotel'nyi Island (middle part of the Munugudzhak Horizon).

Family Vidrioceratidae Plumer et Scott, 1937

Subfamily Vidrioceratinae Plumer et Scott, 1937

Genus *Tabantalites* Ruzhentsev, 1952

Tabantalites etchiensis Andrianov, 1985

Plate, figs. e, f, g; Fig. 3, drawings c and d

Tabantalites etchiensis: Andrianov, 1985, p. 158, Plate VI, fig. 3.

Holotype: no. 55/730; Andrianov, 1985, Plate VI, fig. 3; Yakut Branch Museum, Siberian Division, Russian Academy of Sciences, Yakutsk; northern Verkhoyansk region, Kharaulakh Ridge; left side of the Lena River upstream of the Kubalakh River mouth; Tuora-Sis Formation, Sakmarian Stage.

Shape. Within the first three whorls, the evolute shell having weakly to moderately overlapping whorls is of the ophiocone type (Fig. 3d). Beginning from the fourth, the whorls envelope each other more deeply, and diameter of umbilicus is decreasing. Within the period of fifth to seventh whorls, the shell is involute, strongly swollen, and pachycone in shape. These whorls are almost completely enveloping one another, slowly growing in height. The wide, slightly convex ventral side is merged with gently convex lateral sides, which slope toward umbilicus forming a kind of depression around it. The umbilical shoulder is rounded. The umbilical wall is rather high and convex, having the incrassate shell layer. The cylindrical umbilicus is almost closed.

Specimen no.	Number of whorls	D	H	W	DU	H/D	W/D	DU/D
2/988	6	7.8	4.3	6.9	0.6	51	88	8
	5.5	6.2	3.2	5.2	0.47	50	81	7
	5	5.3	2.7	4.1	0.44	51	77	8
	4.5	4.2	2	3	0.47	49	72	11
	4	3.4	1.6	2.4	0.64	47	71	19
	3.5	2.8	1.1	1.9	0.76	40	68	28
	3	2.2	0.8	1.5	0.88	37	66	39
	2.5	1.8	0.5	1	0.76	30	60	43
	2	1.5	0.4	0.9	0.58	28	60	40

Sculpturing. Shell is decorated with very fine radial striae forming clusters on lower parts of lateral sides (six clusters in one fourth of the sixth whorl). On the ventral side, they form the almost imperceptible sinus.

Lobe line. The lobe line is poorly preserved (Fig. 4c). The first lateral lobe is bicusped, and the second one is tripartite.

Comparison. In contrast to *T. bifurcatus* (Ruzhentsev, 1952, p. 77, Plate VI, figs. 3–7), *Tabantalites etchiensis* has wider whorls and less distinct sculpturing; its evolute stage in ontogeny is shorter (3–3.5 versus 4–4.5 whorls of *T. bifurcatus*).

Distribution: Sakmarian Stage; Tuora-Sis Formation of the Kharaulakh Ridge and Munugudzhak Horizon of the Kotel'nyi Island.

Material: one specimen; northwestern coast of the Kotel'nyi Island; the middle part of the Munugudzhak Horizon.

Reviewers A.S. Alekseev and T.B. Leonova

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Triassic Transgressions, Regressions, and Marine Biota of Northern Siberia

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Abstract—The analysis of transgression and regression curves for 13 facies zones of the Triassic successions in Siberia was carried out for the first time. The established ten transgressive–regressive cycles of the 1st and 2nd orders developed in the early Induan, early Olenekian, terminal late Olenekian, early and late Anisian, early Ladinian, early and late Carnian, early–middle Norian, and also in the Rhaetian. The early Induan, early Olenekian, early Anisian, early Ladinian, early Carnian and early–middle Norian transgressions in the Central Siberian and Verkhoyansk basins were likely controlled by eustatic movements, whereas all other events were probably triggered by tectonic movements. Connections between these movements and changes in basic groups of marine Triassic invertebrates of Siberia are considered. The development of Triassic biota is shown to have been directly dependent on global eustatic movements.

Key words: sea-level fluctuations, marine biota, facies, Triassic, northern Siberia

INTRODUCTION

The Triassic Period in Siberia was characterized by a successive dynamics of sedimentation processes. Accumulation of Triassic deposits in the region, like in the whole Boreal Realm, proceeded in three stages corresponding to stratigraphic epochs (Kazakov, 1991). Each epoch and age begun with a transgression cycle and ended with a regression cycle, i.e., the sea-level fluctuations were most significant at the boundaries between epochs and ages. Most likely, the changes in sedimentation were caused by eustatic movements. Data on some other regions of the world also show connections between the history of the regions, regional biota, and fluctuations of the World Ocean level (Hallam, 1981; Biddle, 1984; Embry, 1988).

When plotting transgression–regression curves and analyzing the water-level fluctuation in the Central Siberian and Verkhoyansk seas (Fig. 1), I considered reference sections of 13 facies zones of the Taimyr, Lena–Anabar, Northern Verkhoyansk, Western Verkhoyansk, Eastern Verkhoyansk and Baky–Nelgekhe structural–facies regions (SFR). These sections are located in the north and east of Mesozoic troughs of the consolidated Siberian continent that is especially important for establishing the eustatic nature of the curves. To make the analysis more complete, other sections located in the platform or along its margins and those of the geosynclinal type were considered as well. It should be pointed out that the Triassic sedimentation in northern Siberia proceeded in settings of the passive continental margin that reduces to a minimum the influence of processes of tectogenesis and volcanism on sea-level fluctuations.

Triassic successions of the region under discussion are composed of terrigenous rocks (sandstone, siltstone, mudstone, clay), except for the lower Olenekian strata made up of organogenic bituminous limestone (the Chekan Formation). In northern Siberia, thickness of Triassic deposits in the platform and subplatform sections varies from 30–100 to 1000–1400 m, reaching 5000–6000 m in the geosynclinal sections (Fig. 2). Triassic sequences are represented by a wide range of facies: from continental and littoral to relatively deep-sea sediments, the formation of which proceeded sometimes beyond the shelf limits. In the study region, the most complete succession of Triassic deposits clearly characterizing cyclic sedimentation is established. Biotas of Triassic sequences of the region had wide paleogeographic connections within the Boreal Realm. The abundance of microfossils in the studied rocks is variable. Paleontological remains are common in the Eastern Taimyr, Lena–Olenek, Lower Lena and Kharaulakh facies zones (FZ). Very rare shells, mainly of bivalves and conchostracans, are found in the Central Taimyr, Lower Vilyui and Tumara facies zones (Fig. 2).

For the Triassic of Siberia, the analysis of transgressive–regressive fluctuations and their interrelations with sea biota in general is given for the first time. The only exception is work by Ermakova (1995) who presented some evidence on changes in the taxonomic composition of the Early Triassic ammonoids from the eastern Verkhoyansk region, where they were caused by the eustatic sea-level fluctuations. I have analyzed

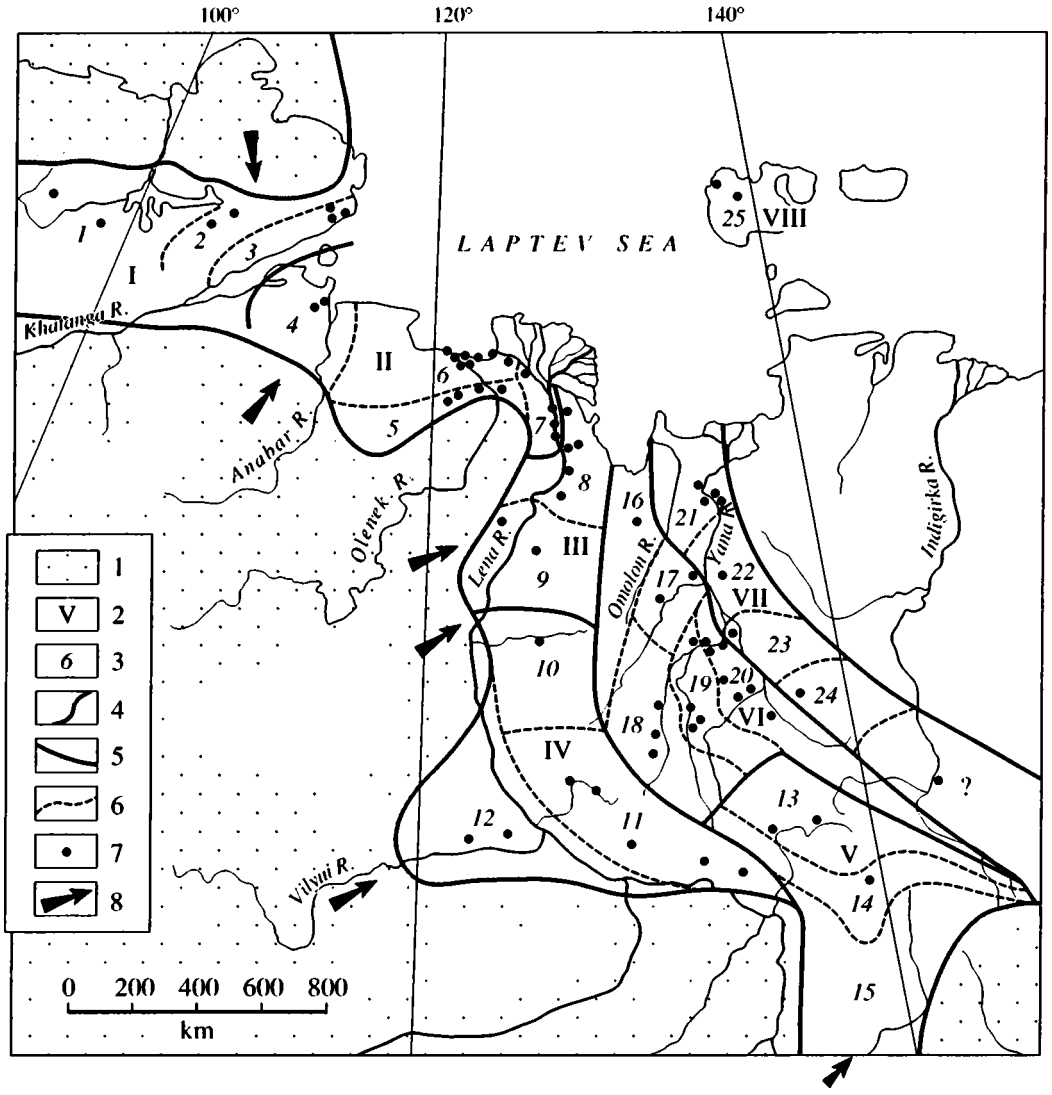

Fig. 1. Structural–facies zoning in northern Siberia and Triassic key sections: (1) land; (2) structural–facies regions; (3) facies zones; (4) boundaries of a hypothetical sedimentation basin; (5) boundaries of structural–facies regions; (6) boundaries of facies zones; (7) main exposures; (8) main drift directions of clastics.

Structural–facies regions: (I) Taimyr; (II) Lena–Anabar; (III) Northern Verkhoyansk, (IV) Western Verkhoyansk; (V) Eastern Verkhoyansk; (VI) Baky–Nelgekhe; (VII) Yana–Kolyma; (VIII) Novosibirsk. Facies zones: *1*, Central Taimyr; *2*, Tulai-Kiryaka; *3*, Eastern Taimyr; *4*, Ust-Anabar; *5*, Buur–Olenek; *6*, Lena–Olenek; *7*, Lower-Lena; *8*, Kharaulakh; *9*, Orulgan; *10*, Mengkere; *11*, Tumara; *12*, Lower-Vilyui; *13*, Tompo; *14*, Dyby; *15*, Yudoma; *16*, Omoloi; *17*, Baky–Bytantai; *18*, Dulgalakh; *19*, Sartang; *20*, Nelgekhe; *21*, Kular; *22*, Mukhtai; *23*, Tuostakh; *24*, Burgavli; *25*, Kotel'nyi.

six facies settings: continental; continental–lagoonal; shallow-water tidal, near the shoreline (the upper subtidal); relatively shallow-water, offshore (the middle subtidal); relatively deep-water (the lower subtidal); and pseudoabyssal (facies of the continental slope). The study was combined with the facies–genetic analysis and reconstruction of sedimentation conditions in the Central Siberian basin in collaboration with Kazakov (Kazakov *et al.*, 1982).

The reconstruction was facilitated by the well-elaborated zonal scheme based on the evolution of ammonoids and bivalves. The scheme allowed the sequences to be reliably correlated at the zonal and infrazonal levels over a long distance (about 4000 km) from the Taimyr Peninsula in the northwest to the Sette Daban spurs in the southeast. All units of the general and regional scales were established in the studied sections. The study of Triassic fauna from northern Siberia made it possible to date all the local lithostratigraphic units. In addition to orthostratigraphic groups, data on autonomous zonal scales were used to verify the reliability of the lateral correlation between the studied cycles. Thus, the availability of detailed zonal scales based on ammonoids and bivalves, as well as the cor-

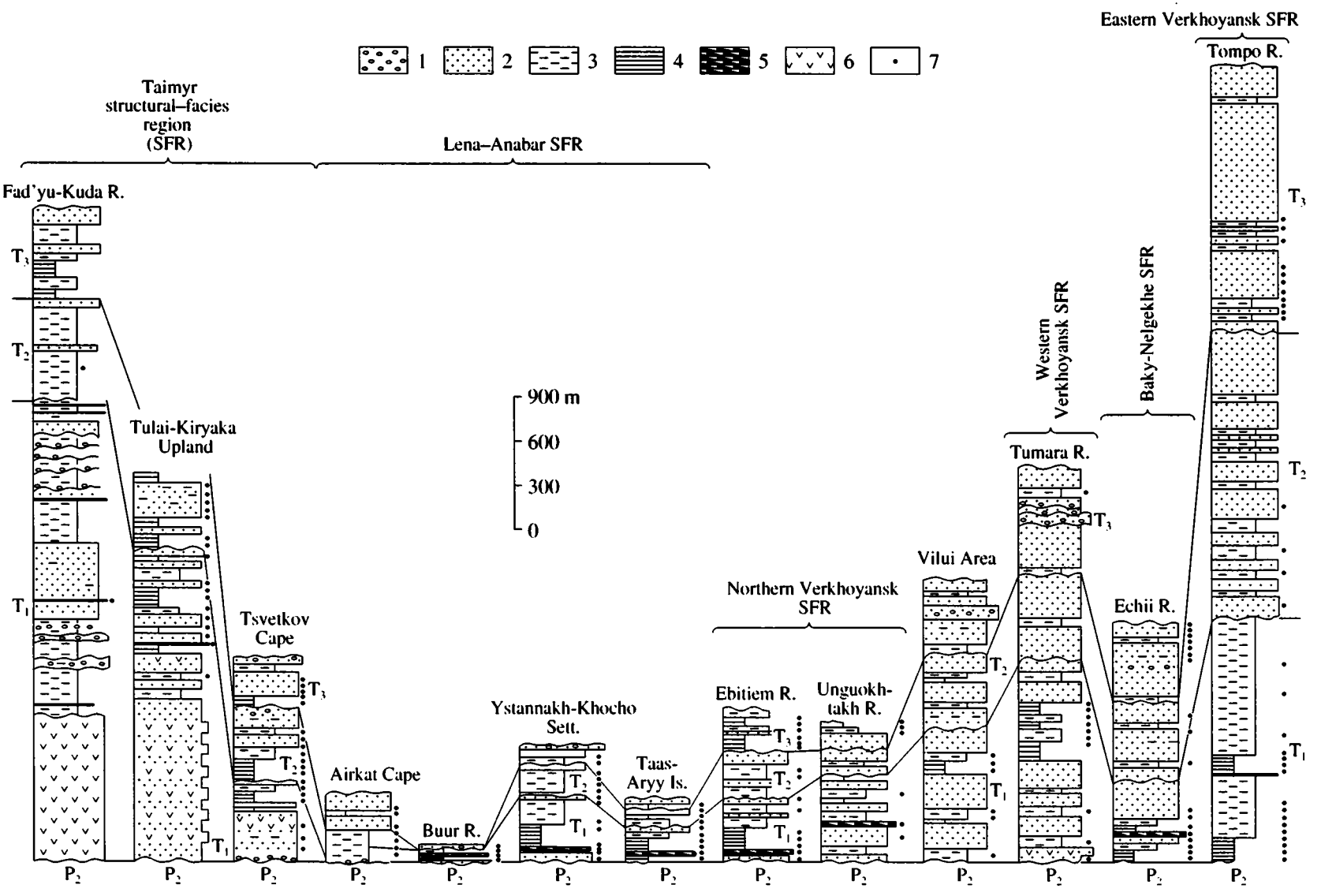

Fig. 2. Schematic lithostratigraphic sections of Triassic deposits in northern Siberia: (1) conglomerate; (2) sandstone; (3) siltstone; (4) mudstone; (5) bituminous or ganogenic limestone; (6) basic volcanic rocks; (7) fossiliferous levels.

relative successive assemblages of other organisms elucidated in most cases the reliable biostratigraphic position of the transgression–regression boundary.

This work presents a general analysis of sea-level fluctuations and related biotic changes in the Central Siberian and Verkhoyansk paleobasins throughout the Triassic period. This is extremely important, because there is a direct relation between the cyclic sedimentation and invasions of some groups of Triassic marine invertebrates from the North Pacific to the Boreal Realm.

RESULTS

The Early Triassic

A hiatus at the boundary between the Permian and Triassic is recognized almost everywhere in the study region, and the Induan begins with sandstone members displaying conglomerate intercalations in all considered sequences, except for that of the Tompo FZ (the Eastern Verkhoyansk SFR). The Induan transgression followed an extensive Late Permian regression that is evident most clearly in the Tompo and Dulgalakh FZs (Fig. 3). The lower Induan deposits are mainly represented there by black mudstone and fine-grained thin-platy siltstone with abundant clayey–carbonate and siliceous–clayey concretions. Traces of the early Induan transgression are poorly exhibited in other regions of Siberia, and shells of macrobenthos are lacking in lagoonal and, to a lesser extent, in littoral facies (Fig. 3). The immigration of ammonoids and bivalves from the Tethys and dominance of common genera in sea basins of various latitudes are related to that transgression. The early Induan molluscan assemblages are similar at the species level in Siberia and the whole Boreal Realm (Ermakova, 1995; Kurushin, 1998a, 1998b; and others).

The gradual expansion of transgression was in progress in northern Central Siberia during the late Induan. A regression phase took place in the southern Verkhoyansk area, where the taxonomic diversity of ammonoids and bivalves decreased. The geographical differentiation of fossils considerably increased. The *Vavilovites* genus dominated among ammonoids and the *Promyalina* and *Atomodesma* forms prevailed among bivalves (Vavilov, 1968; Kurushin, 1991, 1998b; Ermakova, 1995). Nautiloids of that time are unknown (Sobolev, 1989).

The beginning of the transgression largest in the Triassic time corresponds in Siberia to the early Olenekian of (Fig. 3). This event was characterized by a remarkable biota rearrangement and by a wide development of oxygen-deficient environments. The early Olenekian transgression was regarded by some researchers as the maximal one within the Boreal Realm (Kazakov *et al.*, 1982). According to Embry (1988), the maximum sea-level stand in the Canadian Basin was confined to the early Griesbachian (the earliest Induan), whereas the minimum one is recorded exactly in the early Olenekian. According to my reconstructions, the early Olenekian transgression was the largest one during the Triassic in Siberia and northeastern Asia as a whole. Its traces are detectable in all Boreal regions.

The leveling of faunas and wide development of cosmopolitan ammonoid genera and bivalve species, which immigrated from lower latitudes probably due to the climate warming and the sea-level rise, represent characteristic features of the early Olenekian. Diverse nektobenthos and pelagic mollusks were basic components of the biota. Macrobenthos consisted of few genera. Impoverished ammonoid assemblages were represented by endemic species and genera at this substage, except for its *kolymensis* phase (Ermakova, 1995). As compared to the Induan, the taxonomic diversity of assemblages was greater (Fig. 4). Bottom coenoses consisted of few paleoecological groupings. Typical representatives of benthos are missing from facies of bituminous limestone that is most likely a consequence of anaerobic conditions in sediments and on their surface. Sedimentation proceeded on the outer shelf and probably on the continental slope. Bituminous organogenic limestones representing a reliable stratigraphic datum were widespread at that time; age analogues of these limestones are known in some regions of the Tethys. An abrupt change in composition of cosmopolitan species and genera of bivalves, ammonoids, conodonts, and others, took place at the beginning of the early Olenekian (Dagys *et al.*, 1979; Kurushin, 1989, 1991; and others). The lower Olenekian boundary is well expressed having distinct lithological and paleontological features; it is most reliable in the Boreal Triassic.

First regression signs against the background of the terminating early Olenekian transgression are established in the first half of the late Olenekian (Fig. 3). Due to the reduction of Siberian and Boreal basin areas, ammonoid and bivalve assemblages became clearly endemic (Dagys and Kurushin, 1985; Dagys and Ermakova, 1988; Kurushin, 1991, 1998b). Dominant among bivalves were bakevellids and streblopterinellids represented by endemic species, whereas ammonoid assemblages mainly consisted of meekoceratins, keyserlingitids, sibiritids, and olenikitids, which incorporated local genera (Ermakova, 1995; Kurushin, 1998b). The amount of ammonoid genera slightly decreased, whereas the generic diversity of bivalves and brachiopods nearly doubled (Fig. 4). A transgression presumably of local significance is notable against the background of the intensifying regression during the *grambergi* phase and at the beginning of the *spiniplicatus* phase. A somewhat greater number of genera of benthonic mollusks, as compared to the beginning of the late Olenekian, is confined to this transgression. At the end of the Olenekian, the basin became shallower, and this resulted in extinction of a series of taxons and in appearance of sand members with massive textures in the sections (Kazakov *et al.*, 1982).

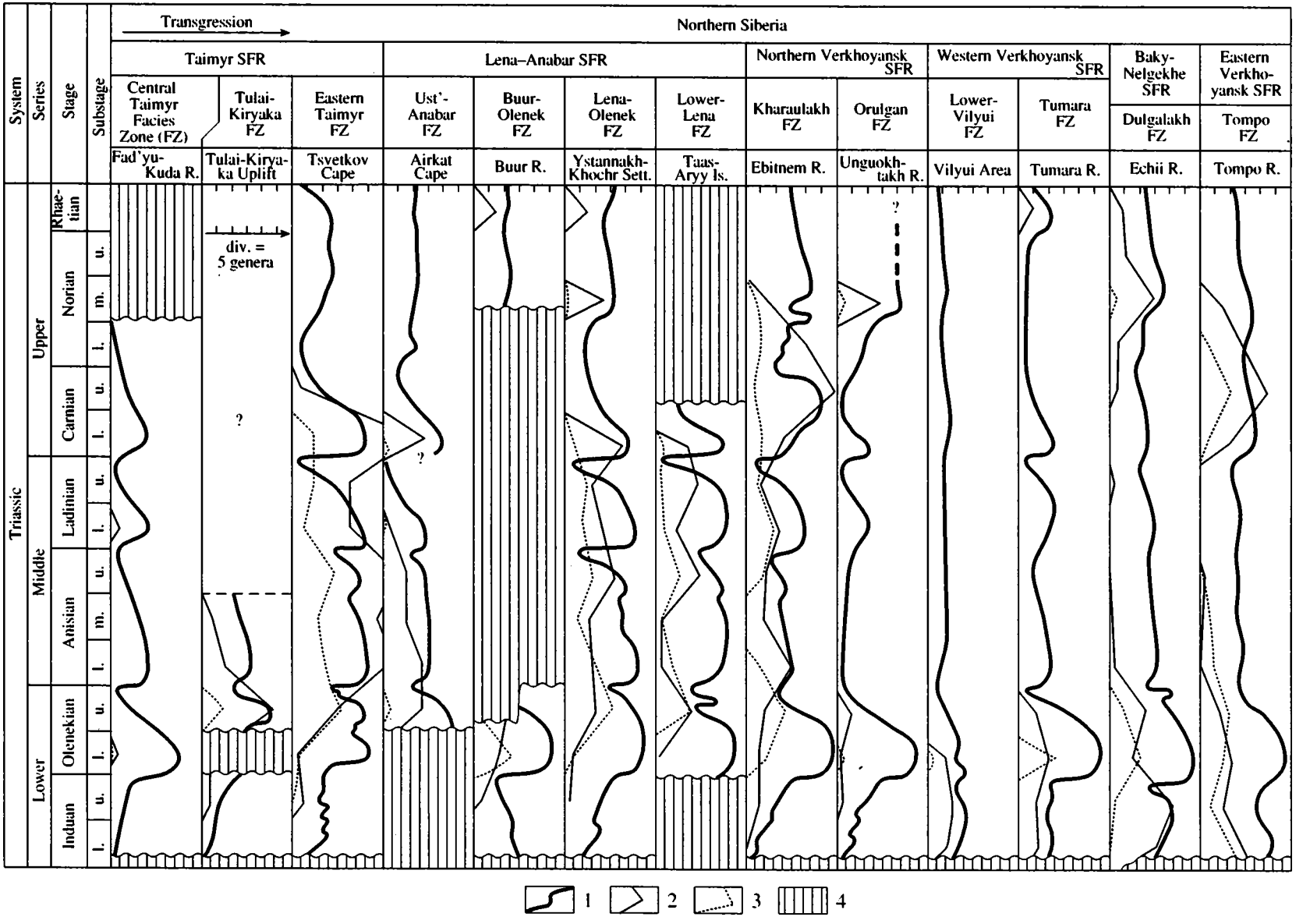

Fig. 3. Transgression–regression curves and the generic diversity dynamics of Triassic macrobenthos, nektobenthos, and pelagic organisms in northern Siberia: (1) transgression–regression curves; (2) abundance of macrobenthos genera; (3) abundance of nektobenthos and pelagic organisms; (4) stratigraphic hiatus.

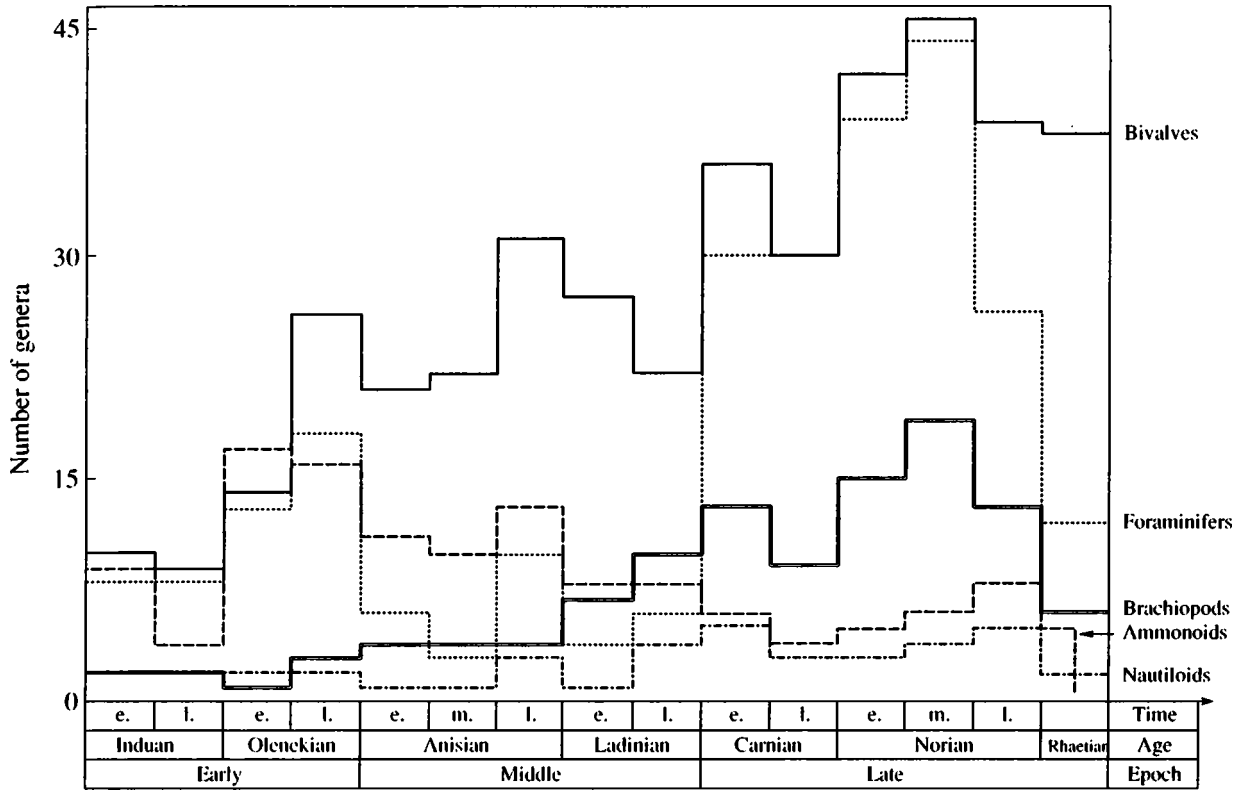

Fig. 4. The generic diversity dynamics of basic groups of the Triassic invertebrates in Siberia.

The Middle Triassic

An extensive transgression occurred at the beginning of the early Anisian. The base of the respective transgressive cycle in sections of northern Siberia is represented by mudstone and clayey siltstone yielding rich invertebrate assemblages (Fig. 2). About a quarter of 18 Boreal ammonoid genera of that time are endemic (Vavilov, 1992). Coeval pelagic mollusks characteristic of many Triassic transgressions are unknown. The taxonomic diversity of benthos and ecological–trophic groupings considerably exceeded that characterizing the early Olenekian transgression. For instance, the number of genera among bivalves of northern Siberia was more than half as much as during the early Olenekian transgression. A similar tendency is seen among brachiopods. At the same time, the number of genera in other fossil groups decreased: the generic diversity of foraminifers reduced half as compared to that of the early Olenekian time, and the number of ammonoid genera decreased from 17 to 11 (Gerke, 1961; Dagys, 1965; Dagys *et al.*, 1979, 1996; and others).

A small-amplitude transgression of the late Anisian time is established in the eastern Taimyr and Lena–Olenek interfluve. It is recorded in the section structure (clayey siltstone) and in compositional changes of faunal assemblages. Beyrichitids became a dominant group among ammonoids (Vavilov, 1992) and posidoniids prevailed among bivalves. The invasion of gymnitids and other groups is also recognized for that time (Dagys *et al.*, 1979; Vavilov, 1983; Konstantinov, 1991; Kurushin and Zakharov, 1995). The immigration of pelagic forms (the *Daonella* genus) from northern regions of the Tethys was characteristic of bivalves. As compared to previous transgressions, the number of genera and paleoecological groupings increased among all sea organisms (Fig. 4).

An extensive transgression, traces of which are observed in all regions of Siberia, occurred in the early Ladinian. No leveling of faunas took place at that time, and molluscan assemblages were represented by endemic species and genera. The generic diversity of most invertebrate groups decreased as compared to that of the late Anisian (Dagys, 1988, Dagys *et al.*, 1996).

A very extensive regression of the latest Ladinian drained a series of land areas in northeastern Asia. Most likely, this landscape rearrangement was determined by tectonic movements. The reduction of sea areas is registered on the global eustatic curve and confirmed by data on the Canadian Basin (Embry, 1988; Haq *et al.*, 1988). An abrupt change in paleogeographic conditions considerably affected all fauna groups. The event resulted in the drastic reduction of taxa of sea biota and, for some groups, in the mass extinction of nearly all their species. However, an increase in the number of genera is noted for other groups, e.g., for brachiopods, nautiloids, and foraminifers (Fig. 4). The geographical

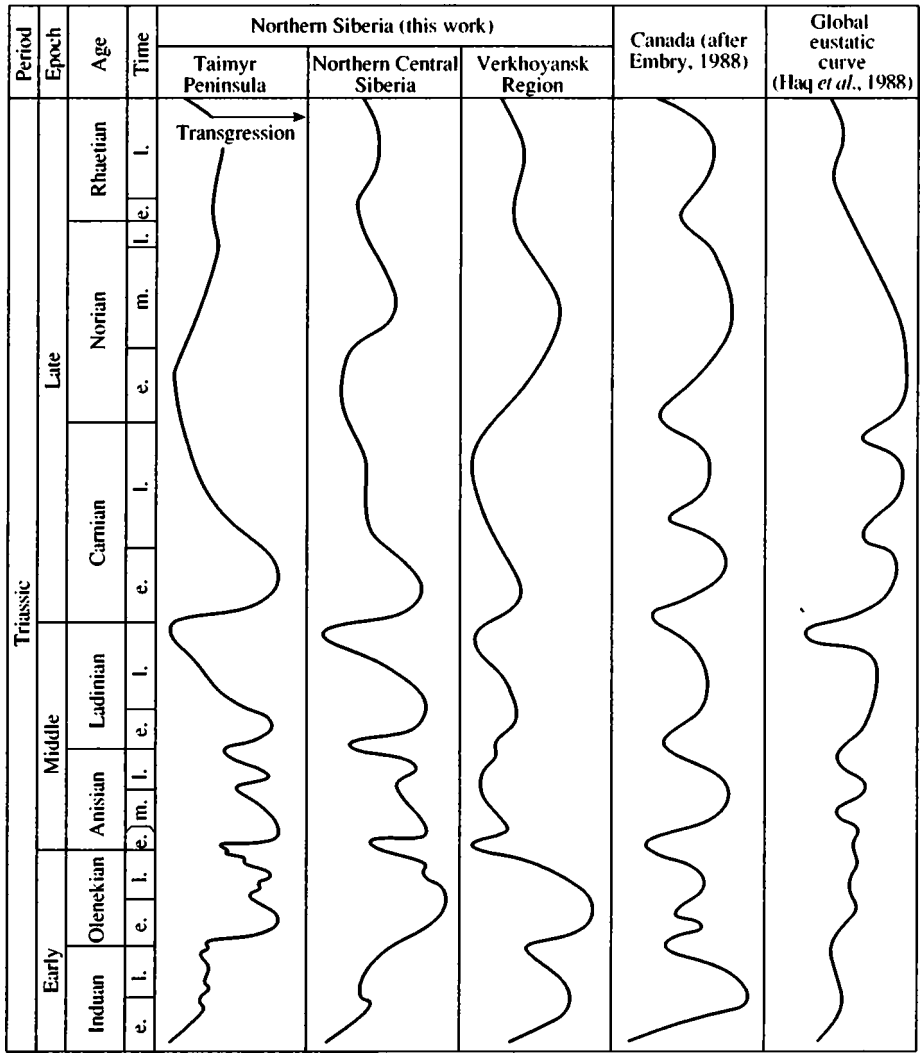

Fig. 5. Diagram of Triassic sea-level fluctuations in some regions.

differentiation of sea invertebrates mainly represented by endemic taxons was distinctly manifested at that time. The end of the late Ladinian is clearly detectable on the basis of transition from marine to continental facies and by taxonomic changes in fossil assemblages.

The Late Triassic

One of the most extensive transgressions throughout Siberia took place at the beginning of the early Carnian (see Fig. 3). Clay sequences with rich assemblages of macro- and microorganisms accumulated at that time. The invasion of halobiids, brought by warm waters from lower latitudes during the *tenuis* phase is notable among bivalves in. Discophyllitids and clydonautilins appeared for the first time (Vavilov, 1992; Dagys and Sobolev, 1992). The time interval under discussion was characterized by a sharp growth of generic diversity of all groups except for ammonoids: by five and six times for nautiloids and foraminifers, correspondingly, by two times for brachiopods, and half as much for bivalves as compared to their diversity in the early Ladinian (Gerke, 1961; Arkhipov, 1974; Dagys and Kurushin, 1985; Sobolev, 1989; Yadrenkin, 1991; Vavilov, 1992; Kurushin, 1992; see Fig. 4). The transgression is reliably recorded by synchronous shifts in the global eustatic curve and in that of the Canadian Basin (Fig. 5).

Sandy rocks of the continental or littoral genesis accumulated in the study region during the late Carnian. The transgressive cycle caused probably by local factors (tectogenesis and so on) is recorded only in the Kharaulakh FZ. As compared to the early Carnian, in the generic diversity biota somewhat decreased. The immigration of typical halobiids (the *Halobia* genus) from lower latitudes was characteristic of pelagic bivalves. On the whole, the regression was in progress from that time until the end of the Triassic being inter-

rupted by small transgressive peaks in individual facies zones: by the late Carnian phase in the Kharaulakh Ridge, by the middle Norian peak in Olenek River basin, Kharaulakh and Orulgan ridges, and by the Rhaetian transgression in the Taimyr Peninsula, Olenek River basin, and some other areas (Fig. 3). Such a general reduction of Siberian and Boreal basin areas was most likely related to the eustatic movements. According to Haq *et al.* (1988), the global sea level tends to decrease from the middle Norian to the end of the Triassic.

One more transgression of the early Norian, with a maximum in the middle Norian, is established in some zones of the Lena–Anabar, Northern Verkhoyansk, Eastern Verkhoyansk and Baky-Nelgekhe SFRs. The invasion of ammonoids and bivalves from the Tethys region was confined to the beginning of this transgression cycle. An abrupt speciation among bivalves (the beginning of the monotids expansion), brachiopods, and foraminifers was typical of that time. The high diversification of genera was probably related to warm water penetration from the North Pacific (Fig. 4).

The generic diversity decreased in the late Norian in response to reduction of Boreal marine areas. A series of ammonoid genera became extinct, halobiids died out, and the geographic range of monotids extremely narrowed at the end of the Norian. Mostly continental and coastal shallow-water deposits accumulated at that time in northern Siberia and other Boreal regions (Franz Josef Land, Spitsbergen, Arctic Canada).

The last, small-amplitude transgression caused probably by local events took place at the beginning of the Rhaetian. On the studied territory, facies of that time are represented by coastal-marine sandy deposits yielding elements of exclusively benthic assemblages. In Siberia, endemic faunas that existed among benthos were limited in geographic distribution by the Olenek River in the northwest and by the Sea of Okhotsk coast in the east. The generic diversity sharply decreased in many Rhaetian faunal groups (Fig. 4). All genera of ammonoids have died out. Bivalves, the most diverse group of the time under consideration, experienced the mass extinction at the generic level (except for two genera) at the turn to the early Lias. The Rhaetian–Hettangian boundary time was characterized by a considerable intensification of tectonic movements, and the enhanced uplift resulted in shoaling of Siberian sea basins. That was one of the main reasons responsible for considerable changes in biota composition.

DISCUSSION

The analysis of cosmopolitan and endemic genera in basic groups of sea organisms, primarily in mollusks, points to the increasing significance of cosmopolitan organisms during transgressions and to the grater role of endemic organisms during regressions. For instance, the highest percent of endemic ammonoid genera is established for the periods of the late Olenekian (71%), late Ladinian (50%), and late Carnian (56%) regressions, whereas their abundance was lower during the late Induan (33%) and late Anisian (29%) regressions. The content of cosmopolitan ammonoid genera was 75% in the early Induan, 82% in the early Olenekian, 78% in the early Anisian, 50% in the early Ladinian, and 40% (?) in the early Carnian. Ammonoids were represented by cosmopolitan genera in the Norian and Rhaetian (Dagys *et al.*, 1979; Konstantinov, 1991; Vavilov, 1992; Ermakova, 1995, and others). Endemism at the generic level among bivalves was insignificant. The highest abundance of endemic bivalve genera was characteristic of the late Ladinian (32%) and late Carnian (23%) regressive cycles. During other regressive events, abundance of endemic genera was very low: 7.4% in the late Olenekian, 13% in the late Induan, 15.4% in the late Norian, and 19% in the late Anisian. At the time of transgressions, cosmopolitan bivalve genera represented on the average up to 90% of their assemblages.

When revealing relationships between the generic diversity dynamics and transgressive–regressive cycles, one can establish some regular trends. Of six transgressions most likely caused by eustatic movements, only two (the early Carnian and the early–middle Norian) turned out to be marked by a high generic diversity. A high generic diversity during the early Induan transgression is characteristic only of the Tompo and Dulgalakh FZs that accumulated the relatively deep-water sediments in offshore areas of the Verkhoyansk Basin adjacent to the North Pacific. At the time of the early Olenekian transgression, a considerable diversity of organisms was typical only of those facies zones, which had connections and fauna exchange with northern regions of the Tethys (the Tumara, Tompo, Dyby, and other zones). A high generic diversity in the mentioned zones during the early Induan and early Olenekian transgressions can probably be explained by penetration of some taxons and warm waters from the North Pacific. The diverse generic composition at the time of the early Anisian transgression is established only in the Eastern Taimyr FZ. During the early Ladinian transgression, the remarkable diversity of genera, especially of benthic ones, was characteristic of three facies zones: Eastern Taimyr, Lena–Olenek, and Kharaulakh (Fig. 3). As for other transgressions related in origin to local events, I should mention here the following. In northern sections of Central Siberia, the diverse generic composition of sea invertebrates is established for sedimentary cycles related to the late Olenekian, late Carnian, and Rhaetian transgressions in the Verkhoyansk FZ. Thus, the considerable generic diversity is established in those transgressive sedimentary cycles, which formed during either the Early Triassic phases of semiarid climate, or the Late Triassic phases of rather warm humid climate that was favorable for penetration of some taxons from the North Pacific. Cold and very humid climate at the

time of the early Anisian and early Ladinian transgressions presumably was responsible for the impoverished generic composition of fossil assemblages.

Thus, seven Triassic transgression of the 1st order, which are distinguished in northern Siberia, took place in the early Induan, early Olenekian, early Anisian, late Anisian, early Ladinian, early Carnian, and early Norian. Transgressions of the 2nd order corresponded in time to the second half of the late Olenekian (eastern Taimyr Peninsula, Lena River lower reaches), the late Carnian (the Kharaulakh Range), and the Rhaetian (all regions). Among the distinguished events, there are transgressions well correlative with the global eustatic fluctuations and with those recorded in the Canadian Basin (Fig. 5). These are the early Induan, early Olenekian, early Anisian, early Ladinian, early Carnian, early–middle Norian, and Rhaetian transgressions.

Transgression peaks in Siberia, which fit best of all the global eustatic curve, correspond to the early Induan, early Olenekian, early Anisian, early Ladinian, early Carnian, early–middle Norian, and Rhaetian. The sea level rises at the beginning of the second half of the late Olenekian and in the late Carnian, which are distinguished in the eastern Taimyr, Kharaulakh Range, and Lena River lower courses, are also well correlative with the global eustatic curve (Fig. 5). Worthy of notice is the fact that configurations of eustatic fluctuation curves for the globe, Siberian and Canadian basins are different, and this is likely related to peculiarities in the history of particular basins, but may reflect as well the different methodological approaches to the reconstruction procedure. In general, the comparability of transgression–regression peaks is good. The best correlative are the North Siberian and Canadian eustatic curves that can be explained by the proximity and free connections between two areas, and also by general features of the Boreal basin history, although both regions represented different Triassic zoochores of the 2nd rank.

It should be pointed out that amplitudes of transgressive peaks in the Siberian, global and Canadian eustatic curves are different. Four peaks of various significance appear to be worthy of mentioning. For instance, the highest global peaks correspond in time to the early Norian, early and late Carnian, and to the early Ladinian. The largest cycles in the Canadian Basin are distinguished in the early Induan, early Anisian, early Carnian, and early Norian. In the Siberian sea basins, major transgressions are confined to the early Olenekian, early Anisian, early Ladinian, and early Carnian. It should be noted as well that some transgression peaks in northern Siberia predate or postdate the global sea-level rises of comparable age. For instance, the late Anisian transgression in Siberia is lagged behind the middle Anisian event of the eustatic sea level rise in the global curve. Furthermore, the early Norian peak in the global curve is displaced relative to the middle Norian peak distinguished in northern Siberia. Similar discrepancies also become evident by comparison of the global and Canadian eustatic curves. Most likely, this is a consequence of imperfect stratigraphic reconstructions and correlation.

CONCLUSION

Ten transgressive–regressive cycles are distinguished in Triassic deposits of the studied territory. These fluctuations directly affected the dynamics of marine invertebrate evolution. Some taxons of basic groups of sea organisms invaded the study region from the Tethys at the onset of many, at least, of seven transgressions (the early Induan, early Olenekian, early Anisian, late Anisian, early Ladinian, early Carnian, and early–middle Norian). The mentioned six transgressions, except for the late Anisian one, are probably of the eustatic origin, whereas others were associated with tectogenesis.

As the transgression cycles and fauna immigration from the low-latitude paleobasins are interconnected, the sea-level fluctuations appear to be of the eustatic origin. Biota turned out to be more uniform in composition during the global sea-level rise. The high generic diversity was characteristic of the early Carnian and early–middle Norian transgressions that developed under warm climatic conditions. A considerable generic diversity also marks the early Induan and early Olenekian transgressions in those facies zones, which had free connections with the North Pacific during the respective periods of warm and dry climate. Impoverished invertebrate assemblages were typical of many facies zones during the early Anisian and early Ladinian transgressions that seems to be a consequence of fairly cool and humid climate. During all the transgressions, the share of cosmopolitan genera among bivalves was very high (90%), whereas the maximum abundance of cosmopolitan genera among ammonoids was during the early Induan, early Olenekian, early Anisian, early–middle Norian and Rhaetian transgressions. The high endemism of the early Ladinian and early Carnian ammonoid assemblages can be explained by termination of the Hercynian tectogenesis in the Ladinian time. In general, the diversification of endemic taxons coincides with terminal phases of the regressive cycles.

The global sea-level fluctuations in the North Siberian basin of the Triassic time controlled the evolution of pelagic and benthic mollusks. This likely indicates that the most important factors were common for abiotic and biotic events and controlled both the accumulation of Triassic sequences and the dynamics of biota evolution.

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Isotopic Age of Rhyolites from the Triassic Tura Group of the Kushmurun Graben, the Turgai Depression

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Abstract—Isotopic dating showed that rhyolites of the Kushmurun graben are divisible into two groups different in age. One group is close to the Induan–Olenekian boundary in its chronostratigraphic position and has K–Ar and Rb–Sr age of 247 ± 3 Ma. The Rb–Sr isochron age for another group is 162 ± 7 Ma and thus corresponds to the Middle Jurassic. The results obtained suggest that the available stratigraphic subdivision of deposits in the Kushmurun graben should be revised. They also elucidate the isotopic age of the Induan–Olenekian boundary.

Key words: rhyolites, isotopic geochronology, Permian, Triassic, Jurassic, Induan and Olenekian stages.

The Lower–Middle Triassic volcanogenic–sedimentary deposits are spread all over the western Siberia, the eastern trans-Urals region included (Bunina, 1961; Bochkarev, 1984; Kirda and Fradkina, 1997; Surkov *et al.*, 1997). They occupy position between the dislocated Paleozoic basement and the Jurassic–Paleogene sedimentary cover, where beds show an almost horizontal attitude. The results of geophysical investigations and deep-drilling data demonstrated that, throughout the region under consideration, the Triassic corresponded to a stage of an intense continental rifting, when magmatic activity was concentrated in the graben-like troughs marking the extension axes in the Earth' crust (Surkov *et al.*, 1997) and striking in the submeridional and northeastern directions (Fig. 1). Despite the variable quantitative proportions (Fig. 2), extrusive and sedimentary rocks are of the constant composition in the troughs and can be correlated across the immense territory from the Turgai depression in the south to the Arctic ocean in the north (Bochkarev, 1984; Kirda and Fradkina, 1997; Surkov *et al.*, 1997).

The volcanogenic–sedimentary fill of troughs is distinguished as the Tura Group ranging in age, according to resolutions of the 5th Interdepartmental Conference on Mesozoic Deposits in the West Siberian Plain, from the terminal Induan to initial Norian (*Resheniya...*, 1990). The Tura Group includes multiple intercalations of predominant extrusive rocks and subordinate variegated terrestrial sediments. The latter are represented by shales, siltstones, and sandstones sporadically tuffaceous and intercalated with thin interlayers of carbonate rocks. Dominant among extrusive rocks are tholeiitic and less abundant subalkaline basalts occurring as lava flows and subvolcanic bodies. Abundance rate of andesites and rhyolites, which are detected in some grabens of the eastern trans-Urals regions (e.g., in the Kushmurun, Dolmatova, and Il'inskii–Borisova troughs) is ca. 10%.

As volcanics are the only stratified rocks, which can be correctly dated using the isotopic methods, it seems rational to date the respective members of the Tura Group in order to solve both the regional stratigraphic problems and the interregional correlation of volcanic events, for instance in the study region and adjacent Tunguska syneclise. In addition, the isotopic dates for volcanics occupying definite stratigraphic levels can provide additional insights into the Phanerozoic time scale (PTS) and, in particular, geochronology of the Permian–Triassic boundary. Considering the last problem as principal one, we approached its solution in this work by means of study rhyolites from the Kushmurun graben.

STRUCTURE, COMPOSITION, AND GEOLOGICAL AGE OF THE TURA GROUP

In the Kushmurun graben of the Turgai depression, volcanogenic–sedimentary rocks of the Tura Group extend, according to drilling data, for the distance of 175 km as a belt 60 km wide. Their thickness varies from 200 to 2000 m. The deposits constitute the bottom and sides of the trough basically filled with the Jurassic coal-bearing sediments. At the site of the Kushmurun brown-coal deposit, an upper portion of the group consists of tholeiitic to subalkaline basalts, basaltic andesites and subordinate andesites alternating in succession and intercalated with sedimentary interlayers of variable thickness (from few to 70 m). In the section pene-

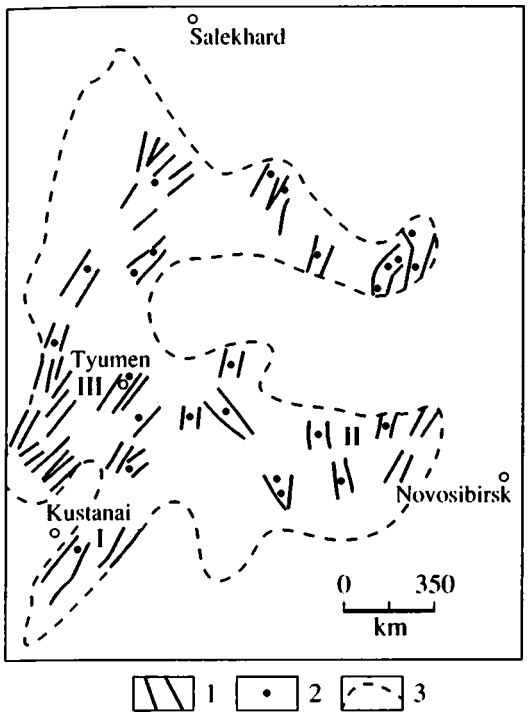

Fig. 1. Distribution of the Lower Triassic Tura Group in western Siberia: (1) rift grabens filled with terrigenous–volcanogenic rocks of the Tura Group; (2) Kushmurun-2c (I), Nikol'skoe (II), and Tyumen (III) boreholes that penetrated the Tura Group; (3) distribution boundaries of the Tura Group rocks.

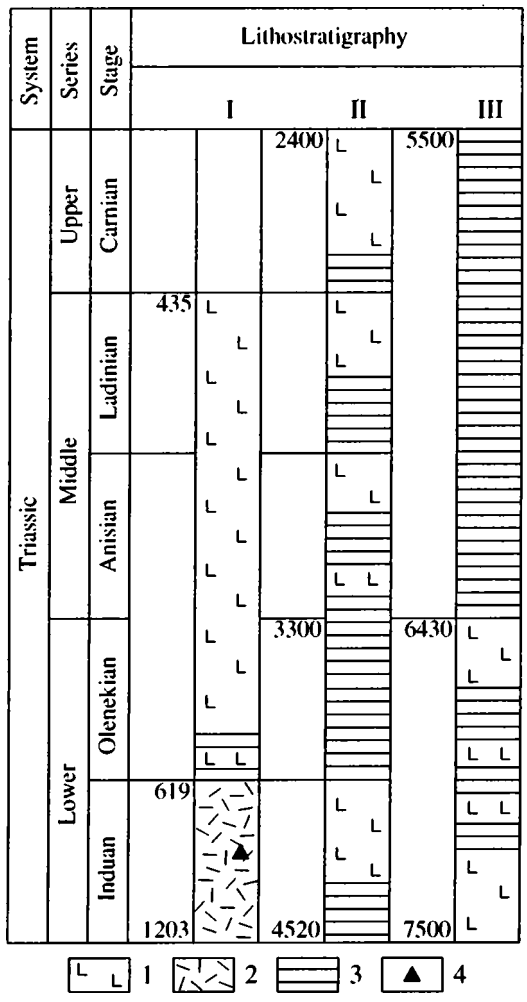

Fig. 2. Correlation scheme of Triassic deposits in the borehole sections Kushmurun-2c (I), Nikol'skoe (II), and Tyumen-SG-6 (III): (1) basalt; (2) rhyolite; (3) terrigenous deposits; (4) sampling site of Lower Triassic rhyolites (figures to the left of columns indicate depth levels of boundaries between particular stratigraphic units).

trated by Borehole 2c, acid volcanic rocks underlying basaltic flows are up to 600 m thick (Bunina and Kuznetsov, 1961). Relationships between acid and basic volcanics remained here unclear for a long time. At the beginning, rhyolites were considered as rocks of the dike and laccolithic facies crosscutting basaltic flows of the Tura Group (Gorskii and Leonenok, 1958). Afterward, K.P. Udris discovered by geological mapping that basaltic flows are intercalated with acid tuffs and breccias. Correspondingly, Bunina and Kuznetsov (1961) decisively attributed rhyolites to lavas underlying the basaltic flows. With respect to acid volcanics, paleontological approach to define their age is useless, because their sequence is free of sedimentary interlayers. At the same time, thin intercalations of rhyolite tuffs and alternation of basaltic and acid lavas, which was originally distinguished by Udris, suggest the almost synchronous deposition of the rhyolite–basalt sequence (Bunina and Kuznetsov, 1961).

The later geological mapping, carried out by the Zelenogorsk expedition in 1969 around the Kushmurun coal-bearing deposits and further to the south, near the Chili Lake, showed that brecciated fluidal rhyolites mixed with basalt fragments occur as well in the upper part of the basaltic sequence and form a kind of extrusive cupolas. These rhyolite bodies are up to 300–500 m thick and to few dozens of meters across. Thus, we can distinguish two rhyolite formations: one situated under and synchronous with lower basalts of the Tura Group, and another crosscutting these basalts and younger in age. Nevertheless, all rhyolites have been considered as one rock generation attributed to the Tura Group.

The time range of the Tura Group in the Kushmurun graben is defined, based on palynological spectra and on occurrence of *Esteria* and fish remains, as ranging from the Early (Induan and Olenekian stages) to Late (Rhaetian Stage) Triassic. Romanovskaya (1959, 1960) considered the lower part of volcanogenic sequence as corresponding in age to the Early Triassic, since spore–pollen assemblages from this interval include *Pleuromeia* forms associated with abundant striate pollen of ancient conifers and Ginkoales, and also with sporadic pollen grains of Cordaitales, *Lebachia*, and *Vittatina*. In

opinion of A.V. Khabakov, concurrent fish remains (equilateral hemiheterocercal caudal fin and scales of oval-rhombohedral shape) exclude any possibility to attribute this part to the Permian, and though Polukhina (1960) distinguished palynospectra from this level, which are characteristic of the Kazanian Stage of the Permian in the taxonomic composition, they were shown to be redeposited (Surkov *et al.*, 1997). However, these redeposited spores and pollen from the basal portion of the Tura Group indicate that the underlying (older) deposits correspond to the Kazanian Stage defining the lower age limit of the group.

Correlation between the Tura Group of the Kushmurun graben and comparable deposits in other regions shows that the magmatic activity in question begun synchronously in a vast territory. In the Chelyabinsk graben, for instance, basal sediments of the group yielded the same remains of the *Palatonistidat* fish group together with species *Esteria subcirenlaris* Tschen., *E. acquale* Lutk., and *Corina papilaria* Lutk. that allowed E.M. Lutkevich to attribute these sediments to the Induan Stage (see in Kareva, 1959). The subsequent resolutions of the 5th Interdepartmental Stratigraphic Conference defined that the maximal age limit of the Tura Group in the Lyapina-Konda, Shekaly, and Aleksandrova areas of western Siberia corresponds to the latest Induan, and the minimal one to the Norian of the Late Triassic (*Reshenіya...*, 1991). In borehole Nikol'skoe-1 drilled the Koyatogorsk–Urengoi graben (northern Omsk region), the depth level of 4519.7 m and interval of 4432.6–4440.5 m yield the Induan pollen-and-spore assemblages (Klimko, 1986), whereas the higher interval of 3795.3–4189.8 m is characterized by the Olenekian palynospectra (Surkov *et al.*, 1997). The Induan age of basal deposits in the Tura Group sequence is established as well in the Nikol'skoe borehole section of western Siberia (Rovnina, 1994) and in the Anokhino graben of the Urals (Tuzhikova, 1983). The superdeep drilling in the Tyumen graben demonstrated that deposits of the Tura Group occupy here the interval from the depth of 6420 m down to the level of 7504 m, where the drilling operations ended. Palynospectra from the upper terrigenous member of the group are of the Early Triassic age without doubts (Surkov *et al.*, 1997). So, the brief review presented above evidence initiation of the volcanic activity, which basically determined composition of the Tura Group, in the Induan Age of the Early Triassic.

Previous isotopic age determinations on volcanic rocks of the Tura group are mostly those done by applying the K–Ar method to the whole-rock samples. From the viewpoint of current geochronology, this approach is incorrect. Among other previous results, we should mention dates of 261 and 268 Ma obtained, using the K–Ar method, by B.M. Naidenov (Kazakh Institute of Mineral Products) for two biotite concentrates extracted from trachyrhyodacites of the Kushmurun graben, where they were recovered by Borehole 2c from the depth of 1073–1075 m (see in Bunina and Kuznetsov, 1961). Significance of these dates is unclear however, because none of the necessary analytical parameters (potassium content, atmospheric argon concentration, and measurement errors) have been reported. At the same time, it is clear that the potassium decay constant used at that time differs from its current value, and we can state *a priori* that the uncertainty of measured dates was too high for the correct solution of stratigraphic problems. In addition, there are dates of 243 (Garris, 1961) and 165 Ma (Ovchinnikov and Garris, 1959) obtained for the whole-rock rhyolite samples from the Kushmurun graben. Additional age values of 190 and 290 Ma are known for the whole-rock rhyolite samples from the Techa graben of the trans-Urals region, and 225–274 Ma for basalts and dolerites of the Tyumen graben (Bochkarev, 1984). Accordingly, all these dates suggest two periods of rock formation, one corresponding to 225–290 Ma, and another to 165–190 Ma. These age intervals will be discussed below, but we feel it necessary to mention here that the younger age values were interpreted as a result of rock alteration under influence of hydrothermal–metasomatic processes of the Jurassic–Cretaceous time (Bochkarev, 1984).

INVESTIGATION RESULTS

In this work, we studied the rhyolite samples, characterizing the lava sequence that underlies the Tura Group basalts of the Kushmurun graben (Sample 2^2 from the depth of 1080 m, Borehole 2c; see Fig. 2), and others from the minor subvolcanic bodies crosscutting these basalts (Sample 312-2 from the depth of 133 m, Borehole 3c at the site of the Kushmurun coal-bearing deposit, and three samples from the depth interval of 90–125 m penetrated by several boreholes southward of the coal-bearing deposit in the Chili exploration area). Samples from subvolcanic bodies were collected by geologists of the Zelenogorsk Expedition in 1971.

Acid rocks below the basalts and those crosscutting them are cenotypal, lacking signs of metasomatic alterations. In its composition, Sample 2^2 corresponds to trachyrhyodacite (SiO_2 = 71.1%, Na_2O = 3.38%, K_2O = 5.38%). This phyric rock consists of quartz, sanidine, biotite, and plagioclase phenocrysts set in felsitic groundmass. In the age determination procedure, we used the whole-rock sample and extracted biotite, K-feldspar, and plagioclase fractions.

Rocks crosscutting the Tura group basalts are more acid in composition and have lower contents of alkali and aluminum. Their more crystalline ground mass is sometimes of the fluidal texture. Quartz is dominant mineral of phenocrysts, and biotite is frequently missing. Whole-rock samples of these rocks were studied using the Rb–Sr method only.

The K–Ar age determinations were carried out for biotite and K-feldspar fractions of Sample 2^2. The biotite fraction was analyzed under guidance of

M.M. Arakelyants at the Isotopic Laboratory of the Institute of Geology of Ore deposits, Petrography, Mineralogy, and Geochemistry, Russian Academy of Sciences (IGEM RAN). Potassium concentrations were measured with precision 0.5% using the flame photometry method. Radiogenic Ar concentrations were determined by the isotopic dilution method using mass spectrometer MI-1201-IG in a static regime; the analytical error is less than 1%. The K–Ar age of K-feldspar was measured at the Department of Isotopic Geology, VSEGEI, in accord with the standard procedure (*Metodicheskie...*, 1983). The results obtained are presented in Table 1.

Sample 2^2 and its biotite, K-feldspar, and plagioclase fractions were also studied, using the Rb–Sr method, at the Laboratory of Geochronology, IGGD RAN. The isotope dilution method was used to measure the Rb and Sr concentrations. The mixed ^{85}Rb–^{84}Sr tracer was added to the pulverized material prior to its decomposition in the mixture of nitric and fluoric acids. The cation-exchange chromatography and resin AG5OW-X8 were used to extract rubidium and strontium for isotopic analysis with the eight-collector mass spectrometer MAT-261. The measured values were normalized to $^{88}Sr/^{86}Sr = 8.37521$ in order to be corrected for the Sr isotope fractionation. The normalized ratios were matched with $^{87}Sr/^{86}Sr = 0.71025$ characterizing the international standard NBS-987. The analytical error for Rb and Sr concentrations measured in the studied samples is 0.5%. The laboratory contamination levels are 0.03 ng for Rb and 2 ng for Sr. Average values of six analytical results for the national standard sample PSH-70a are as follows: Rb = 524 ppm, Sr = 65.5 ppm, $^{87}Rb/^{86}Sr = 24.1$, $^{87}Sr/^{86}Sr = 1.20048 \pm 0.00012$. The same values of four results for the international standard BCR-1 are Rb = 45.9 ppm, Sr = 329 ppm, $^{87}Rb/^{86}Sr = 0.4027$, and $^{87}Sr/^{86}Sr = 0.70501 \pm 0.00002$. All presented errors correspond to 2σ.

The results of Rb–Sr analysis of Sample 2^2 are presented in Table 2 along with data on the whole-rock samples from other boreholes, which were obtained using the standard procedure (*Metodicheskie...*, 1983) and mass spectrometer MI-1201T at VSEGEI. The isochron parameters are calculated using the ISOPLOT program (Ludwig, 1990). By calculations, we applied the following levels of measurement errors: 1.0% for $^{87}Rb/^{86}Sr$ and 0.05% for $^{87}Sr/^{86}Sr$, as corresponding to the precision level of the Rb–Sr analysis performed at IGGD RAN, and, respectively, 2,0 and 0.05% for the same parameters measured at VSEGEI.

Consideration of K-Ar data (Table 1) allows us to state that the age value of 248 ± 3 Ma calculated for biotite corresponds to a real geological event, as the measured K-feldspar age is almost identical (the latter is however characterized by a much greater analytical error, and we exclude this result from further discussion). The results of Rb–Sr analysis turned out to be somewhat surprising, because the respective plot of

Table 1. Analytical K–Ar data on rhyolites from the Kushmurun graben

Sample no. and rock fraction	K, %	$^{40}Ar_{rad}$, ppb	T_{meas}, Ma
2^2: Bt	7.34	135.5	248 ± 3
KFSp	7.40	141.6	257 ± 12

Abbreviations in tables 1 and 2: (Bt) biotite; (KFS) K-feldspar; (Pl) plagioclase; (WR) whole rock.

Table 2. Rb–Sr isotopic data on rhyolites from the Kushmurun graben

Sample no. and rock fraction		Rb, ppm	Sr, ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
2^2	WR	159.6	65.45	7.0722	0.73315 ± 1
	KFSp	162.6	162.1	2.9052	0.71872 ± 1
	Pl	85.3	210.5	1.1727	0.71256 ± 1
	Bt	331.2	7.35	138.50	1.19250 ± 6
312-2	WR	73	141	1.587	0.71455 ± 33
814-3	WR	180	100	5.006	0.72224 ± 16
831	WR	78	40	5.720	0.72379 ± 31
1108-1	WR	88	36	7.726	0.72893 ± 40

data points (Fig. 3) reveals two different correlation trends on the Rb–Sr evolutionary diagram. The slope angle of isochron approximating all data points, which characterize Sample 2^2 and its constituent minerals, corresponds to the age of 245.6 ± 2.3 Ma and initial isotopic ratio (IR) $^{87}Sr/^{86}Sr = 0.7085 \pm 0.0001$, MSWD = 0.13. The very low MSWD value means the strict linear correlation of data points (Fig. 3). It is also remarkable that the isochron age is dependent not only on the biotite data point characterized by the highest Rb/Sr and $^{87}Sr/^{86}Sr$ ratios. Almost identical results, namely, the age value of 245 ± 7 Ma and IR = 0.7085 ± 0.0002, are calculated for three other data points despite of the higher MSWD = 0.25 and, consequently, of the greater uncertainty reflecting the narrower variation range of measured parameters. The result obtained should be definitely interpreted as corresponding to the age of a real geological event, because the isochron approximates data points for the whole-rock and minerals with variable tolerance for natural impacts. Another group of data points characterizing rhyolites, which crosscut the basaltic sequence, defines its own isochron with the age value of 162 ± 7 Ma and IR = 0.7108 ± 0.0005, MSWD = 1.3.

DISCUSSION

Age values calculated for Sample 2^2 on the basis of two different approaches are concordant within the analytical error and uncertainty limits of both methods. They are also consistent with available age determina-

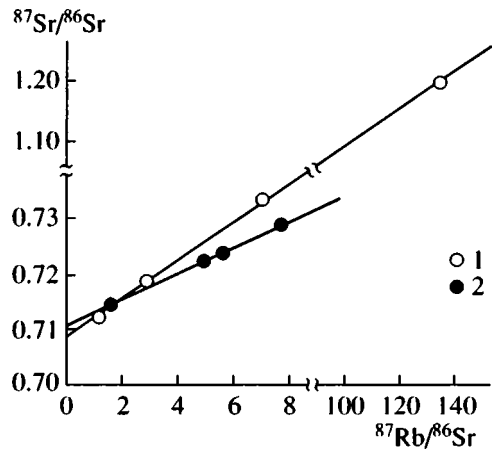

Fig. 3. Rb–Sr isochron plot for the studied rhyolites: (1) rhyolite lavas below basalts, T = 245.6 ± 2.3 Ma; (2) rhyolite bodies crosscutting basalts, T = 162 ± 7 Ma.

tions based on paleontological data, and this, together with the rock freshness in petrographic aspect, suggests that the calculated isotopic ages depict the formation time of the studied rhyolite lava. This event can be dated back to 247 ± 3 Ma (2σ), i.e., to the average value calculated from two results under consideration.

In our opinion, the isochron age of 162 ± 7 Ma probably corresponds, in the geological sense, to the formation time of intrusive rhyolites, the analyzed samples of which lack signs of secondary alterations and characterize minor bodies crosscutting the Tura Group basalts. An indirect evidence suggesting the time difference between formation of these bodies and lower rhyolite lavas is a minor but stable compositional difference between them, as well as the considerable contrast with respect to their initial $^{87}Sr/^{86}Sr$ ratios (0.7085 versus 0.7108). In addition, the date in question corresponds to the time of intense volcanic processes in some other areas, for instance, in the Mongol–Okhotsk volcanic belt. Moreover, manifestations of Jurassic magmatic activity are established now directly in the Urals and within the eastern trans-Urals region (Rappoport and Barannikov, 1997). Unfortunately, these data do not prove undeniably that the studied rhyolite samples belong to two discrete groups of different age, but such a conclusion seems to be quite realistic, as it explains the aforementioned two groupings of K–Ar dates for the whole-rock samples of the Tura Group, though this can be explained as well by the impact of secondary alterations experienced by rocks at the appropriate stage. Thus, the problem needs to be studied more carefully in the future.

The established formation time of rhyolites from the base of the Tura Group can elucidate, nevertheless, the Induan–Olenekian boundary isotopic age. Stratigraphic position of these rocks (inside the Induan Stage, most likely, close to its termination) suggests that the boundary in question is somewhat younger than 247 ± 3 Ma and, as we shall see below, should not be outside the indicated uncertainty limits. Taking into account this limiting parameter, some problems concerning the stratigraphic position of rhyolites in the Kushmurun graben, and the most reliable date for the Ladinian–Anisian boundary, we believe that the Induan–Olenekian boundary should be dated at 246 ± 2 Ma. At any rate, presently, the above data seem to be the best estimation of the isotopic age of the Induan–Olenekian boundary and can be included into the PTS until the moment, when either the Tura Group rhyolite stratigraphy will be refined, or the other objects related to that boundary will be dated by isotopic methods.

In connection with the results obtained, we can also consider the problem of isotopic age of the Permian–Triassic boundary. It is clear that this boundary is older than 247 Ma. This well agrees with the date included by Odin (1994) into the PTS on the basis of dating results obtained by Claoue-Long *et al.* (1991) and equal to 251.2 ± 3.4 Ma. However, it was already mentioned (Rublev, 1996) that the last date is disputable owing to some shortcomings of the applied determination procedure. Indirectly, we can estimate the isotopic age of the Permian–Triassic boundary using our date for the Induan–Olenekian boundary and the results of Brack *et al.* (1996), who concluded that the Anisian–Ladinian boundary in the Middle Triassic is insignificantly older than 241.2 ± 0.8 Ma. Accordingly, the isotopic age of the Permian–Triassic boundary could be 249 Ma, if the Induan Age was as long the Anisian and Olenekian ages in average (about 3 m.y.).

The last assessment is based on two assumptions: (1) ages of the Early and Middle Triassic were approximately equal in duration; (2) boundary dates used for the assessment are not altered by secondary processes. The first assumption is rather doubtful, however. The careful analysis of isotopic–geochronological data used in the PTS shows that the time-ranges of the stages vary approximately from 1 to 20 m.y., even if we deal with stages of one period. The average duration of a stage in the PTS is no less than 6 m.y., and therefore age value of 249 Ma appears to be the minimum acceptable date for the Permian–Triassic boundary.

In order to discuss the problem of the Permian–Triassic boundary more particularly, we should first compare the dates obtained with other results of isotopic–geochronological studies on the Permian–Triassic volcanogenic sequence of the Siberian platform. Earlier than beginning of the 1990s, geochronological information characterizing this sequence was limited by K–Ar dates for whole-rock samples, which are of a low geological significance. In some recent works of foreign researchers, there were published new age determinations for volcanics from the Tunguska syneclise, mostly from the Noril'sk region of the latter. The new dates have been obtained using the ^{40}Ar–^{39}Ar method, as applied to the whole-rock samples and mineral fractions (plagioclase, biotite, and amphibole) of basalts,

and the SHRIMP U–Pb age determinations for zircons from gabbroids of the Noril'sk intrusion. We cannot take these dates for granted because of some peculiar properties of the applied methods, which should not be considered here. One of them is nevertheless pertinent to our discussion. As it is established (Campbell *et al.*, 1992; Renne, 1995), the Noril'sk intrusion is most likely 252 ± 2 Ma old. As this intrusion is younger than the basaltic sequence of the Ivakino Formation, the latter should be older than 252 Ma. According to most recent data, the Ivakino Formation could be as old as 255 Ma (Zolotukhin *et al.*, 1996). If the quoted age values are correct, we can conclude that the commencement of volcanic activity, which produced the Tura Group, differs by 6–10 m.y. from the volcanism initiation in the Siberian platform.

Turning once again to the estimated isotopic age of the Permian–Triassic boundary, we should stress that the value of 249 Ma corresponds to its upper age limit. The corresponding lower limit can be inferred from data on the volcanic Ivakino Formation of the Noril'sk region. If this formation is really as old as 255 Ma, then the Permian–Triassic boundary must be somewhat younger, as the majority of researchers attribute this formation to the Upper Permian. Consequently, geochronological parameters of the Permian–Triassic boundary can be estimated as corresponding either to the time interval of 249–255 Ma, or to the age of 252 ± 3 Ma. Exactly this level should be accepted at present until its further, more accurate evaluation with the help of more appropriate objects.

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Foraminiferal Zones of the Boreal Berriasian, Valanginian, and Lower Hauterivian in Northern Siberia (Relatively Deep Sea Facies)

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Abstract—The analysis of stratigraphic distribution of foraminifers in the type section of the boreal Berriasian, Valanginian, and lower Hauterivian in the Nordvik Peninsula (the northern part of East Siberia) allowed recognition of the following succession of beds with foraminifers: *Trochammminoides emeljanzevi–Recurvoides praeobskiensis, Recurvoides romanovae, Recurvoides obskiensis, Evolutinella grandis, Recurvoides tigjanikus*, and *Cribrostomoides concavoides*, four of which (beds with *R. romanovae, R. obskiensis, E. grandis, R. tigjanikus*) are distinguished for the first time. Fragments of this succession are studied in the lower Neocomian sections in northern localities of East Siberia: the Tigyan-Yuryakh River, eastern coast of the Anabar Bay, and Bol'shoi Begichev Island. The complete succession of these beds is characteristic of the Surgut area in West Siberia. The age of beds with foraminifers is established on the basis of ammonite and buchia zones. Taking into consideration the consistent boundaries of recognized beds and steadiness of their stratigraphic ranges throughout the large region, the beds are ranked as foraminiferal zones. The foraminiferal zones of northern Siberia are correlated with beds bearing foraminifers in the northern Caspian region, Pechora basin, and Barents Sea plate. Based on characteristic morphological types of foraminiferal tests and species diversity, five successive groupings are established in the considered time interval, which are interpreted to represent paleoecological foraminiferal assemblages. The latter are named after the dominant taxon. Stratigraphic intervals enclosing these assemblages (stratoecotones) are considered as correlative units of sequences composed of different facies. The new species *Cribrostomoides praevolubilis, Recurvoides tigjanikus*, and *R. nordvikensis* are described.

Key words: benthic foraminifers, biostratigraphic zone, boreal Berriasian, Valanginian, Hauterivian, Lower Cretaceous, Siberia.

INTRODUCTION

Elaboration of zonal scales based on different fossil groups represents one of the urgent problems of the boreal Mesozoic biostratigraphy (Zakharov *et al.*, 1997). Foraminifers, along with other microfossils, always played a leading role in solving the stratigraphic problems, particularly when studying unexposed sections. It is quite natural therefore that the significance of foraminifers for the stratigraphy of Lower Cretaceous marine deposits in Siberia was first understood when studying the core material of deep drilling (Zaspelova, 1948; Balakhmatova *et al.*, 1960; Gerke, 1961; Subbotina *et al.*, 1964). Nonetheless, detailed stratigraphic works in connection with oil and gas prospecting required a more accurate dating of beds with foraminifers. The dating could be refined only on the basis of ammonites, belemnites, and bivalves occurring in the same beds. The success of foraminifer-based stratigraphic studies in the 1960s had its origin precisely in the fact that they were closely connected with elaboration on zonal molluscan scales based on the materials from natural exposures of the boreal Berriasian (BB), Valanginian, and Hauterivian in the northern part of Siberia (Sharovskaya, 1966; Basov, 1967, 1968; Saks, 1972; Basov *et al.*, 1983, 1989; Bulynnikova *et al.*, 1981; and others). Recognition of the assemblages, beds with foraminifers, and foraminiferal zones was performed at that time in the best sections of the Lower Neocomian, which served as the basis for elaboration of molluscan zonal scales.

The section of the boreal Berriasian located in the Nordvik (formerly, Paksa) Peninsula is one of such sections (Fig. 1). The section is most complete, with regard to stratigraphy and lithology, in the area of the boreal-type deposits and is recommended as the BB stratotype. (Zakharov and Bogomolov, 1997). At this site, a single exposure reveals a succession of ammonite- and buchia-based zones most complete in the northern regions of Eurasia and North America in the stratigraphic interval from the uppermost middle Volgian Stage to the basal Hauterivian, except for the upper Valanginian, which is either unexposed or truncated by the fault (Zakharov *et al.*, 1983; Bogomolov, 1989). Taking into consideration the aforesaid, as well the fact that

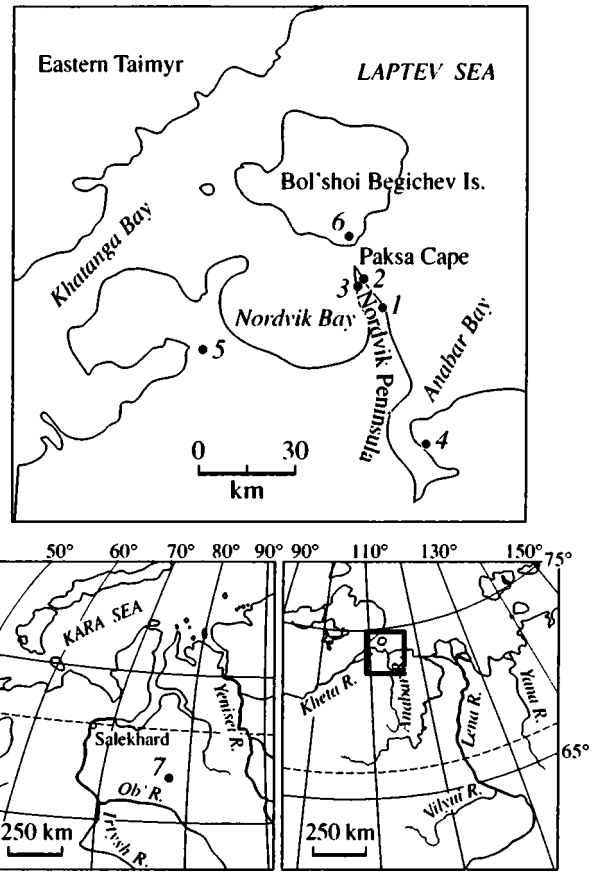


Fig. 1. Localities of considered sections of the boreal Berriasian, Valanginian, and Hauterivian deposits in the northern East Siberia: (*1*) Exposure 33, (*2*) Exposure 35, and (*3*) Exposure 36 in the Nordvik Peninsula; (*4*) the eastern coast of the Anabar Bay, Exposure 1A; (*5*) the Tigyan-Yuryakh River, Exposures 1 and 2; (*6*) Bol'shoi Begichev Is.; (*7*) West Siberia, boreholes in the Surgut area (rectangle shows the general geographic position of the upper map).

constituent rocks (clay and silty clay) accumulated in a central relatively deep part of the paleobasin (Zakharov and Yudovnyi, 1974), this section is most suitable for elaboration of autonomous biostratigraphic scales based on microfossils for the relatively deep-sea facies of the boreal Berriasian.

The first data on foraminifers were reported by Sharovskaya and Basov (1961) and Sharovskaya (1966), who used the collection by Emel'yantsev and Ershov (1953) from the Upper Jurassic–Lower Neocomian section of the Nordvik Peninsula. When describing the same section after the field works of 1967, Basov and Ivanova (Basov *et al.*, 1970) published the list of foraminifers for every member. Later these authors revised the taxonomic composition of foraminifers and stratigraphic interpretation of their assemblages. As a result, they distinguished four stratigraphic units in the rank of beds with foraminifers within the upper Volgian Substage, boreal Berriasian, and lower Valanginian. Every of these units was characterized by a peculiar foraminiferal assemblage (Basov and Ivanova, 1972, Table 24). Later, Bulynnikova (1981) proposed another variant of subdivision of the section in question. The latter variant was officially accepted (*Resheniya...*, 1981). Ten years later, Bokova and Ivanova (1991) proposed to subdivide the upper part of the boreal Berriasian and boreal lower Valanginian of northern Siberia into three units (beds with fauna): *Gaudryina gerkei* (corresponding to the *Surites analogus* Zone), *Pseudolamarkina tatarica* (interval of *Bojarkia mesezhnikovi* and *Temnoptychites syzranicus* zones), and *Globulina* spp. (interval from the base of the *Polyptichites michalskii* and higher). Taking into consideration the aforesaid, we use here the nomenclature of beds suggested by Basov and Bulynnikova with indication of the assumed stratigraphic range in members described by Zakharov *et al.* (1983) (Table 1).

Beds with *Haplophragmoides fimbriatus* (=*Trochamminoides emeljanzevi*)–*Trochammina rosaceaformis* were distinguished by Basov and Ivanova (1972) within the upper Volgian Substage and basal Berriasian (Members VIII–IX; hereinafter numbers of members are given after Zakharov *et al.*, 1983). Bulynnikova (1981) united probably the same members into Beds with *Schleiferella volosatovi* (=*Trochamminoides emeljanzevi*)–*Trochammina septentrionalis* and Beds with *Schleiferella volosatovi*–*Ammodscus veteranus* (Table 1). The species *Trochammina rosaceaformis* Rom., *T. septentrionalis* Schar., and *Ammodiscus veteranus* Kos. are recorded in the lower part of the boreal Berriasian as single specimens. The characteristic feature of these units is an extreme abundance of representatives of the genus *Trochamminoides*.

Beds with *Gaudryina gerkei* (=*Gaudryinopsis gerkei* (Vas.))–*Trochammina parviloculata* (Basov and Ivanova, 1972) as well as Beds with *Recurvoides obskiensis* (Bulynnikova, 1981) correspond to the middle portion of the boreal Berriasian section (Members X–XII) (Table 1). The species *Trochammina parviloculata* Gerke episodically occurs in the boreal Berriasian section beginning from its base. The lower boundary corresponds to the level, where Assemblage I is replaced by Assemblage II, and where abundant representatives of the genus *Gaudryinopsis* appear.

The lower boundary of Beds with *Ammobaculites* spp.–*Gaudryina gerkei*–*Trochammina parviloculata* (Basov and Ivanova, 1972) or Beds with *Ammobaculites gerkei*–*Lenticulina gudinae* (Bulynnikova, 1981) coincides with the base of Member XIII (Table 1). Like all foraminiferal forms with calcareous tests, *Lenticulina gudinae* E. Ivanova is an accessory species episodically occurring in the boreal Berriasian and Valanginian deposits. Therefore, the lower boundary of this unit is drawn based on the increased proportion of genera *Gaudryinopsis* and *Ammobaculites* representatives, i.e., at the replacement level of foraminiferal Assemblage II by Assemblage III.

Table 1. Lithostratigraphic scheme of the boreal lower Neocomian sections in the Nordvik Peninsula (the Anabar Bay of the Laptev Sea) into beds with foraminifers (symbols for lithology as in Fig. 3)

Stage	Substage	Ammonite zones and beds (Zakharov *et al.*, 1997)	Buchia-based zones (Zakharov *et al.*, 1997)	Member	Thickness, m	Beds with foraminifer: Basov and Ivanova, 1972	Bulynnikova, 1981	Proposed scheme
Hauterivian	lower		*Buchia crassicollis*	XXIV	4.0	Not defined	Not defined	Foraminifers are missing
				XXIII	27.0			*Cribrostomoides concavoides*
				XXII	10.0			
Valanginian	lower	Beani	*Buchia sublaevis*	XXI	7.0			
		Ramulicosta		XX	12.0		*Pseudolamarkina tatarica Glomospirella intrita*	*Recurvoides tigjanikus*
		Astieriptychus	*Buchia keyserlingi*	XIX	20.0			
		Quadrifidus		XVIII	20.8			
		Klimovskiensis	*Buchia inflata*	XXII	17.5			*Evolutinella grandis*
Berriasian		Tolli		XVI	17.4	*Reinholdella tatarica Haplophragmoides* ex gr. *latidorsatus*	*Ammobaculitas gerkei Lenticulina gudinae*	*Recurvoides obskiensis*
		Mesezhnikowi	*Buchia tolmatschowi* / *Buchia volgensis*	XV	10.7			
				XIV	7.8	*Ammobaculites* spp. *Gaudryina gerkei Trochammina parviloculata*		*Recurvoides romanovae*
		Analogus	*B. jasikovi*	XIII	4.7			
		Kochi	*Buchia okensis*	XII	2.7	*Gaudryina gerkei Trochammina parviloculata*	*Schleiferella volossatovi Ammodiscus veteranus*	*Recurvoides obskiensis G. gerkei*
				XI	3.6			
				X	3.4			
		Sibiricus	*Buchia unschensis*	IX	4.0			*S. volossatovi Trochammina septentrionalis*
J_3v	u.	Chetae		VIII	1.2	*Haplophragmoides fimbriatus Trochammina rosaceaformis*		*T. emeljanzevi R. praeobskiensis*
		Taimyrensis		VII				

Beds with *Reinholdella tatarica* (=*Valanginella tatarica* (Rom))–*Haplophragmoides* ex gr. *latidorsatus* (=*Cribrostomoides* spp.)) (Basov and Ivanova, 1972) comprise Members XIV–XVIII corresponding to two upper ammonite zones of the boreal Berriasian (*Bojarkia mesezhnikovi* and *Tollia tolli*) and two lower zones of the lower Valanginian (*Neotollia klimovskiensis* and *Propolyptychites quadrifidus*) (Table 1). The index species *Valanginella tatarica* occurs in the boreal Berriasian and Valanginian as single specimens and recognition of the unit is substantiated by abundant representatives of the genus *Cribrostomoides*.

Bulynnikova (1981) defined, in upper part of the boreal Berriasian, the Beds with *Ammobaculites gerkei* and *Lenticulina gudinae* corresponding to the interval of *Surites analogus–Tollia tolli* ammonite zones (Members XIII–XVI) and Beds with *Pseudolamarkina tatarica* (=*Valanginella tatarica*)–*Glomospirella intrita* (Members XVII–XX of the lower Valanginian) (Table 1). The lower boundary corresponds to the appearance level of representatives of the genus *Glomospirella* at the base of Member XVII, where this event accompanies the replacement of Assemblage III by Assemblage IV.

As will be shown below, beds with foraminifers defined by Basov and Ivanova, as well as the scale of Bulynnikova proposed for the boreal Berriasian and lower Valanginian in the Nordvik Peninsula are based on the succession of foraminiferal assemblages, which are facies-dependent to a significant extent. Similar foraminiferal assemblages are registered in the Valanginian sections of the Anabar and Tigyan rivers and in Bol'shoi Begichev Island, because they are located close to the area in question and correspond to a single facies zone (Fig. 1); nonetheless, the intra- and interfacies correlation potential of these assemblage is low.

MATERIALS AND METHODS

The collection sampled by V.A. Marinov in the bed-by-bed manner from the section of the Nordvik Peninsula in 1989 served as a basis for this study. The additional comparative materials from the boreal Berriasian and Valanginian sections of the Tigyan River, Anabar River, and Bol'shoi Begichev Is. were donated by K.V. Zverev, Yu.I. Bogomolov, and M.A. Levchuk, respectively. A.V. Yadrenkin donated samples of drill cores from the Surgut area of West Siberia. Numbers of beds and members, as well as subdivision of sections into formations and zones, are given in accord with a series of publications (Saks *et al.*, 1972; *Resheniya 3-go...*, 1981; Zakharov *et al.*, 1983; Bogomolov, 1989).

Describing the structure of complexes, we used, according to the accepted regulations (Bigon *et al.*, 1989, pp. 117–118), indices of the taxonomic diversity (Simpson index D) and distribution evenness (E).

$D = 1/\Sigma p_i^2$, $E = D/S$ where p_i is the occurrence frequency of the i-species, S is species diversity (the number of species in the assemblage).

Classification of taxons higher in rank than species is given after Podobina (1978).

FORAMINIFERAL COMPLEXES AND ASSEMBLAGES

As is noted above, the section in the Nordvik Peninsula was selected for elaboration of the foraminiferal zonal scale of the boreal Berriasian and Valanginian. First, the stratigraphic distribution of every species through the section was established, and then, stratigraphically isolated groups of species that are referred to as the complexes were defined. In total, six such complexes were distinguished. Every of them correspond to different stratigraphic intervals and are characterized by the peculiar species composition and proportions of constituent species. Our complexes, as well as those defined by our forerunners, likely reflect the taxonomic composition of biocoenotic assemblages. This assumption is based on previous reconstructions and facies analysis (Zakharov and Yudovnyi, 1974). According to the results of this study, the black-shale, locally highly carbonaceous sequence in the Nordvik Peninsula accumulated in the central part of the relatively deep sea basin under the oxygen deficiency in the bottom water layer during the late Volgian and early Barremian time. Tanathocoenoses that were established using the taphonomic analysis of oryctocoenoses are considered in most cases as autochthonous, or displaced only slightly. It was shown that macrobenthic communities occupied flattened bottom areas and were characterized by the laterally stable structure. Clayey and clayey–silty rocks enclosing fossils reveal only thin horizontal parallel lamination without signs of hiatuses (Zakharov and Yudovnyi, 1974). Thus, these results of taphonomic and sedimentological studies imply the autochthonous burial of foraminiferal shells. Consequently, it can be assumed with a fair degree of confidence that succession of complexes in the section reveals the replacement of foraminiferal assemblages with time. The replacement of assemblages was accompanied by changes in the composition and structure of foraminiferal communities that was caused by both the environmental changes and the evolutionary transformations of the species composition. The composition of dominant species represents one of the main characteristics of the assemblage.

The preponderance of particular taxons is most commonly thought to be related to environmental changes. Changes in composition of the dominant group of taxons occur at certain stratigraphic levels. Precisely these changes are considered to represent the most important biostratigraphic events (Krassilov *et al.*, 1985, p. 45). On the basis of this parameter, stratigraphic intervals with the most frequent occurrence of the species (epiboles) are defined in the section. Epiboles are of a great stratigraphic importance, therefore it seems reasonable to consider the hierarchy of taxa dominance in assemblages.

Taxons demonstrating the highest occurrence frequency are suggested to be referred to as the dominants of the complex. The dominant group unites taxons typical of the complex. They are characterized by the high occurrence frequency (as a rule, 5–10% and more) and usually represent no less than 50% of the total number of taxons and at least 90% of the total test abundance. The accessory group includes taxons with the low occurrence frequency (2% and less). This group includes more than a half of taxons, but less than 10% of the total taxa number (Fig. 2).

The composition of the dominant group represents a main characteristic of the complex. The complexes, or taxocoenoses according to Saidova (1976), have a certain hierarchy depending on the rank of taxons used for their description; they can be defined as ordero-coenoses or subordinate familecoenoses and genocoenoses. The complexes (and assemblages) are named after dominant taxons. As a rule, there are more than one dominant species in the complexes, and names of

two and more taxons usually constitute the complex name.

To characterize ecological and ethological peculiarities of species, we used the morphological–functional classification of foraminiferal tests described by Korsun *et al.* (1994).

Morphological group I includes species with flat–convex tests, which are referred to the epifauna populating the compact substrate. By the feeding mode, they are sestonophages extracting food particles from bottom waters or collecting them from the sediment surface.

Morphological group II comprises species with flattened, lenticular test, which represent dwellers of the flocculated layer enriched in organic matter.

Morphological group III consists of species with high conical (fusiform, torpedo-like, according to Korsun) elongated tests probably belonging to vagile representatives of the infauna, i.e., to detritophages dwelling within the soft sediment enriched in organic matter.

Morphological group IV is composed of species with nonspecialized ellipsoidal tests belonging to slightly mobile dwellers of the subsurface sedimentary layer and bottom vegetation.

Based on peculiarities of the taxonomic composition, six foraminiferal complexes named after the dominant taxons are established to successively replace each other throughout the section.

The Early Neocomian succession of foraminiferal assemblages characterized by the gradual increase in the taxonomic diversity can probably be explained by intensification of bottom hydrodynamics related to the general Berriasian–Hauterivian sea regression in the northern areas of East and West Siberia.

SUCCESSION OF FORAMINIFERAL COMPLEXES IN THE LOWER NEOCOMIAN SECTION OF THE NORDVIK PENINSULA

As a result of study on foraminifers from the Neocomian deposits of the Nordvik Peninsula, six their complexes were discriminated and their stratigraphic ranges were established (Fig. 3).

The replacement of one foraminiferal complex by another does not take place at some noticeable surface in the section, but usually occurs within a certain stratigraphic interval of recurrent alternation of the preceding and succeeding complexes. In terms of paleoecology, this interval should be considered as a stratoecoton and here is the main difference between foraminiferal complexes and beds with foraminifers. As will be shown below, the lower boundary of beds with foraminifers is determined by a particular level in the section coinciding with the first appearance of certain biostratigraphic feature, e.g., with the first occurrence of species or with its epibole (the "golden spike" principle).

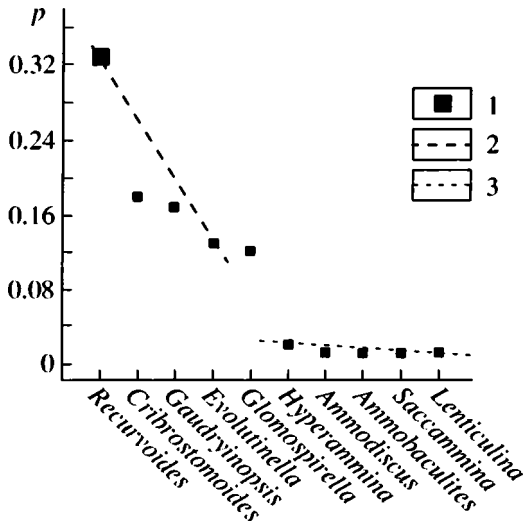


Fig. 2. The structure of foraminiferal assemblages from Sample 29-32-89 (Nordvik Peninsula, Exposure 33, Member XVII. *Neotollia klimovskiensis* Zone): (1) dominant taxon of the assemblage; (2) dominant group of the assemblage; (3) accessory group of the assemblage; (p) occurrence frequency.

The stratigraphic interval in question (Berriasian–Hauterivian) is characterized by the stable composition of defined complexes at the generic level. The only exception could be the disappearance of the genus *Trochamminoides* from the group of dominant taxons of the haplophragmoidid complex in the lower part of the boreal Berriasian (the ammonite *Analogus* Zone). However, data on other Neocomian sections did not confirm this fact so far. It is not inconceivable that the assemblage with *Trochamminoides* represents a specific facies variety of the haplophragmoidid complex.

Complex I (haplophragmoidid; Members VIII–IX)

Assemblage with *Trochamminoides*

Preponderant are representatives of the family Haplophragmoididae. Only one species of the genus *Trochamminoides*, namely *T. emeljanzevi* (Schl.), represents 50–90% of all specimens in the complex. The dominant group also includes genera *Evolutinella* (5–17%) and *Recurvoides* (4–10%). Representatives of genera *Orientalia(?)* (1–3, sometimes 17%) and *Saccammina* (1–2, sometimes 15%) are accessory, but episodically they are rather abundant. The accessory group includes species of genera *Hyperammina, Cribrostomoides, Gaudryinoides*, and *Trochammina* (1–3%).

The taxonomic diversity of the complex is low, D = 1.2–2.5, and the distribution evenness E = 0.23–0.25.

The assemblage includes only forms with tests of the nonspecialized morphological type (morphological group IV).

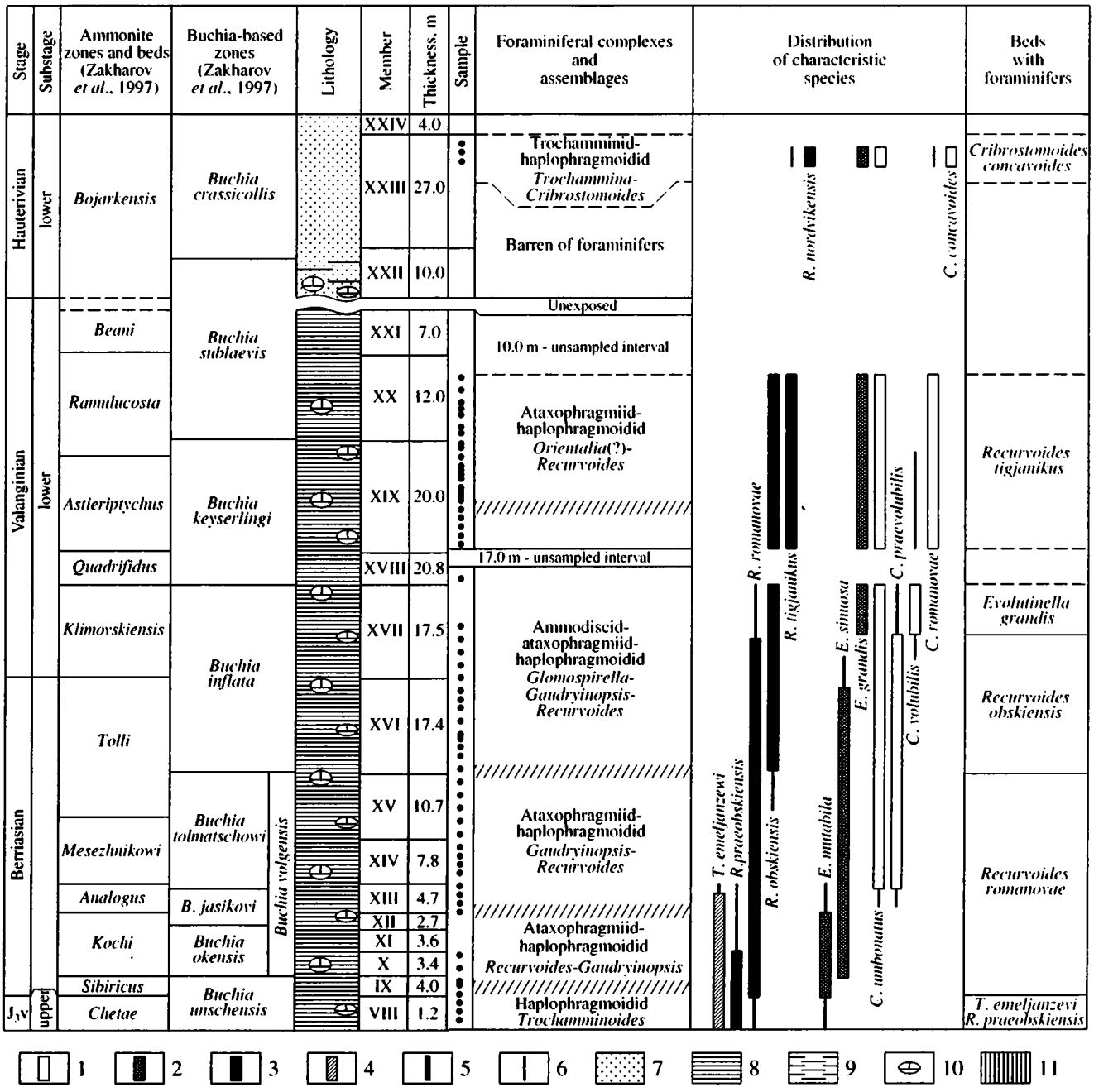


Fig. 3. Stratigraphic distribution of characteristic foraminiferal species, foraminiferal complexes, and beds with foraminifers in the section of the boreal Berriasian, lower Valanginian, and lower Hauterivian in the Nordvik Peninsula (northern East Siberia): (1) genus *Cribrostomoides*, (2) genus *Evolutinella*, (3) genus *Recurvoides*, (4) genus *Trochamminoides*, and (5) other taxons of the dominant group; (6) accessory taxons; (7) siltstone, sandstone; (8) argillite-like clay; (9) clayey siltstone; (10) carbonate concretions; (11) hiatus. Oblique hatchure designates stratoecotone.

The high occurrence frequency of the dominant species *Trochamminoides emeljanzevi* is most likely related to the oxygen deficiency in the bottom water layer of the early Berriasian Khatanga sea. It is not inconceivable that the subsurface sediments were contaminated with H_2S, because most of the tests are pyritized (Zakharov and Yudovnyi, 1874).

Complex II (ataxophragmiid–haplophragmoidid; Members X–XII)

Assemblage with *Gaudryinopsis–Recurvoides*

Dominant are representatives of the family Haplophragmoididae (85%). The dominant group includes genera *Recurvoides* (18–52%), *Evolutinella* (10–45%), *Trochamminoides* (5–15%), *Kutsevella* (to 7%) (family

Haplophragmoididae); *Gaudryinopsis* (6%) (family Ataxophragmiidae). The accessory group consists of species representing genera *Saccammina, Trochammina, Lenticulina*, and *Astacolus*.

The taxonomic diversity of the complex D = 3.5–3.8; the distribution evenness E = 0.38–0.42.

Characteristic morphological types of tests: nonspecialized (morphological group IV; 85%) and elongated, torpedo-like (subcylindrical) (morphological group III; 6%). The characteristic forms of the complex are infaunal detritophages (*Gaudryinopsis*).

Complex III (ataxophragmiid–haplophragmoidid; Members XIII–XV)

Assemblage with *Gaudryinopsis–Recurvoides*

Dominant are representatives of the family Haplophragmoididae (80%). The dominant group consists of genera *Recurvoides* (35–50%), *Evolutinella* (5–14%), *Cribrostomoides* (10–20%) (family Haplophragmoididae), and *Gudryinopsis* (6–8%) (family Ataxophragmiidae). Sometimes, they coexist with representatives of genera *Glomospirella* (9%) and *Lenticulina* (10%). The accessory group includes species of genera *Saccammina, Ammobaculites, Astacolus, Pseudonodosaria, Marginulina, Geinitzinita*, and *Valanginella*.

The taxonomic diversity of the complex D = 5.0–5.5; the distribution evenness E = 0.35–0.50.

Characteristic morphological types of tests: nonspecialized (morphological group IV; 80%) and elongated, torpedo-like (morphological group III; 10%). In contrast to Complex II, this one shows a higher proportion of representatives of the vagile infauna with elongated torpedo-like test (genus *Gaudryinopsis*). The dominant group of species includes representatives of the genus *Cribrostomoides* with the compact involute test characterized by a low number of chambers in the last whorl (7–9).

Complex IV (ammodiscid–ataxophragmiid–haplophragmoidid; Member XVI–lower part of Member XIX)

Assemblage with *Glomospirella–Gaudryinopsis–Recurvoides*

Dominant are representatives of the family Haplophragmoididae (60–70%). The dominant group consists of genera *Recurvoides* (34–40, sometimes 70%), *Cribrostomoides* (13–24%), *Evolutinella* (12–27%) (family Haplophragmoididae), *Gudryinopsis* (18%) (family Ataxophragmiidae), and *Glomospirella* (10–15%) (family Ammodiscidae). The accessory group includes species of genera *Saccammina, Ammobaculites, Lenticulina, Astacolus, Dentalina, Marginulina, Frondicularia, Valanginella*, and *Epistomina*.

The taxonomic diversity of the complex D = 6.0–9.0; the distribution evenness E = 0.60–0.75.

Characteristic morphological types of tests: nonspecialized (morphological group IV; 70%), elongated, torpedo-like (morphological group III; 20%), and flattened lenticular (morphological group II; 10–15%). Unlike Complex III, this one is characterized by the enhanced role of vagile representatives of the infauna dwelling on the soft clayey substrate (genus *Gaudryinopsis*). Also present are flattened lenticular tests of detritophages dwelling in the upper liquid sediment layer (genus *Glomospirella*).

Complex V (ataxophragmiid–haplophragmoidid; Members XIX–XX)

Assemblage with *Orientalia(?)–Recurvoides*

Dominant are representatives of the family Haplophragmoididae (75%). The dominant group consists of genera *Recurvoides* (24–42%), *Cribrostomoides* (7–10%), *Evolutinella* (9–20%) (family Haplophragmoididae), and *Orientalia(?)* (15-20%) (family Ataxophragmiidae). Sometimes, they associate with representatives of genera *Gaudryinopsis* (to 14%). The accessory group includes species of genera *Bathysiphon, Glomospirella, Trochammina, Lenticulina, Astacolus, Pseudonodosaria, Marginulina, Geinitzinita, Valanginella*, and *Epistomina*.

The taxonomic diversity of the complex D = 5.2–7.5; the distribution evenness E = 0.50–0.53.

Characteristic morphological types of tests: nonspecialized (morphological group IV; 75%), flat–convex (morphological group I; 10–15%), and elongated torpedo-like (morphological group III; 10%). As compared with Complex IV, the considered complex is characterized by the lower share of forms dwelling on the soft substrate (genus *Gaudryinopsis*). Present are flat–convex cap-shaped tests of epifaunal species dwelling on the compact substrate: genus *Orientalia(?)*. The dominant group lacks dwellers of the liquid surface sediment layer: genus *Glomospirella*.

Complex VI (trochamminid–haplophragmoidid; Members XIX–XX)

Assemblage with *Trochammina–Cribrostomoides*

Dominant are representatives of the family Haplophragmoididae (75%). The dominant group consists of genera *Cribrostomoides* (41%), *Recurvoides* (24%), *Evolutinella, Kutsevella* (6%) (family Haplophragmoididae), and *Trochammina* (7%) (family Trochamminidae). The accessory group includes species of genera *Lenticulina, Astacolus, Marginulina*, and *Geinitzinita*.

The taxonomic diversity of the complex D = 6.7; the distribution evenness: E = 0.44.

Characteristic morphological types of tests: nonspecialized (morphological group IV; 85%), flat–convex (morphological group I; 7%), and elongated torpedo-like (morphological group III; 7%).

Unlike the previous complex, the considered one lacks dwellers of the liquid surface sediment layer (genus *Glomospirella*). The dominant group also lacks species dwelling on the soft substrate, whereas epifaunal forms dwelling on the compact substrate are represented by the genus *Trochammina*.

Thus, the Neocomian section of the Nordvik Peninsula encloses a succession of foraminiferal assemblages reflecting the regressive replacement of facies. The stratigraphic intervals (stratoecotones) sandwiched between complexes (assemblages) can be useful for correlation of members within the distribution range of monofacies sequences.

BEDS WITH FORAMINIFERS IN THE BOREAL BERRIASIAN, VALANGINIAN, AND BOREAL HAUTERIVIAN OF THE NORDVIK PENINSULA

In our opinion, one of the main tasks, when elaborating the zonal scale based on foraminifers, is analysis of composition and structure of assemblages in order to discriminate their taxons representing the same phylogenetic lineage. As in case of orthostratigraphic groups, foraminiferal taxons selected for the scale construction should be facies-independent and characterized by a high radiation rate, clear diagnostic features, wide geographic distribution, and high abundance in the sections. The first stage of such a study, i.e., the establishment of a succession of biostratigraphic units in a particular section or area, is usually accompanied by discrimination of beds with fauna (*Stratigraficheskii kodeks...*, 1992).

In our study, beds with foraminifers were distinguished using stratigraphic complexes defined in the boreal Berriasian, Valanginian, and boreal Hauterivian of the Nordvik Peninsula and composed of representatives of genera *Recurvoides, Cribrostomoides*, and *Evolutinella*. It is assumed that north Siberian successions of species belonging to the above-mentioned genera characterize continuous phylogenetic lineages. Species of precisely these genera meet requirements of orthostratigraphic groups. They show sufficiently high rates of morphogenesis and are dominants or constituents of dominant groups in most assemblages (Fig. 3).

The distinguished biostratigraphic units corresponds partly to acme-zones of characteristic species. The lower boundaries of zones are substantiated by a complex of features. The latter include, as a rule, levels of the first species occurrence in the dominant group, levels of species transition from the accessory group into the dominant one, and vice versa.

Beds with Trochamminoides emeljanzevi–Recurvoides praeobskiensis

Member VIII. The thickness is 1.2 m.

Gerke (1957) was first to propose Beds with *Haplophragmoides emeljanzevi (=Trochamminoides emeljanzevi)* in northern Siberia as a unit corresponding to "the upper part of the Upper Jurassic (Kimmeridgian–upper Volgian)". Sharovskaya and Basov (1961) specified the position of their lower boundary in the section of the Urdyuk-Khaya Cape as lying "directly above beds with *Craspedites okensis*". Basov (1968) changed the rank of the beds correlating them with the entire upper Volgian Substage and widened their nomenclature (*H. emeljanzevi, Trochammina rosacea, T. septentrionalis*). Later, Basov and Ivanova (1972) correlated the beds only with two zones of the upper Volgian Substage (*Craspedites taimyrensis* and *Chetaites chetae*) coupled with the lower zone of the boreal Berriasian (*Ch. sibiricus*); they renamed the unit as Beds with *Trochammina rosaceaformis–Haplophragmoides fimbriatus*). We propose to change the nomenclature once again and to term the unit as Beds with *Trochamminoides emeljanzevi–Recurvoides praeobskiensis*, inasmuch as both index species are constituents of the dominant group, whereas *Trochammina rosaceaformis* Rom. is an accessory form. Species *T. fimbriatus* (Schar.), characterized by the same stratigraphic range as *T. emeljanzevi*, represents, in our opinion, a microspheric form of the latter.

Beds with *Trochamminoides emeljanzevi–Recurvoides praeobskiensis* are of monotonous lithologically being composed of thin-platty laminated dark gray clay with brown shading, which yields foraminiferal complex of uniform structure and composition sharply dominated by one species *T. emeljanzevi* (Schl.). The genus *Evolutinella* is represented by species *E. mutabila* and *E. schleiferi* (Schar.) occurring approximately in equal abundances. The genus *Recurvoides* includes species *R. praeobskiensis* (Plate, Figs. 1–3) and *R. romanovae* (Plate, Figs. 4 and 5). Species *Orientalia(?) baccula* Schleifer and *Saccammina* sp. occur episodically. Species *Hyperammina* sp., *Cribrostomoides* sp. indet., *Gaudryinopsis gerkei* (Vassilenko), and *Trochammina* cf. *parviloculata* Gerke et Scharovskaja are recorded as single specimens. Calcareous tests are absent.

Beds with Recurvoides romanovae

Members IX–XV (lower part). The thickness is 36.9 m.

The unit is proposed for the first time. Beds are composed of bluish gray argillite-like clays displaying angular jointing and alternating with thin-platty brownish gray clays, which exhibit horizons of limy concretions and pyrite nodules. The lower boundary of the unit corresponds to the base of the acme-zone of the index species. Slightly higher (the lower part of Member X), species *Evolutinella sinuosa* (Bulynn.) becomes dominant. At the base of Member XIII, species *Evolutinella mutabila* (Bulynn.) and *Recurvoides praeobskiensis* Dain et Bulynn. loss their dominant role turning into accessory forms. Beds correlate with the boreal Berriasian, the *Tollia tolli* Zone excluded.

Beds with Recurvoides obskiensis

Members XV (upper part) and XVII (lower part). The thickness is 27 m.

The unit is proposed for the first time as an equivalent of *Tollia tolli* and *Neotollia klimovskiensis* ammonite zones. The beds are composed of argillite-like dark gray clay with horizons of concretions of clayey limestone. The lower boundary of the unit corresponds to the level, where the index species is dominant.

Characteristic species: *Evolutinella sinuosa* (Bulynn.), *Cribrostomoides praevolubilis* Marinov, sp. nov. (Plate, Figs. 9, 10), and *Recurvoides obskiensis* Rom. (Plate I, Fig. 6).

Note to the nomenclature. The species name *Recurvoides obskiensis* was used by Bulynnikova (1981) to designate Beds with *Recurvoides obskiensis–Gaudryina gerkei* in the basal part of the boreal Berriasian of the Nordvik Peninsula, and later by Basov *et al.* (1989), when they subdivided the boreal Berriasian section in the southern Barents Sea basin. In our opinion, they all mistook the megaspheric forms of another species *R. romanovae* for *R. obskiensis.*

Beds with Evolutinella grandis

Members XVII (upper part)–XVIII. The thickness is 10.5 m.

The unit is proposed for the first time. The beds are composed of dark gray argillite-like silty clay and clayey siltstone with large concretions of clayey limestone.

The lower boundary is drawn slightly above the base of the *Neotollia klimovskiensis* Zone at the level, where the index species becomes dominant. In Member XVII, the accessory species is *Cribrostomoides volubilis* (Rom.) (Plate, Fig. 12), whereas *Cribrostomoides praevolubilis* and *Evolutinella sinuosa* become extinct. Characteristic species: *Evolutinella grandis* (Bulynn.), *Cribrostomoides volubilis*, and *Recurvoides obskiensis* (Rom.).

Beds with Recurvoides tigjanikus

Members XIX–XX. The thickness is 32 m.

The unit is proposed for the first time. The base of the unit has not been observed (the section interval of about 17 m was covered by ice and, thus, was not sampled).

The beds are composed of gray to dark gray silty clay alternating with clayey silt bearing large concretions of clayey limestone. The lower boundary corresponds with the level, where the index species is dominant. The dominant group of the complex includes *Recurvoides tigjanikus* Marinov, sp. nov. (Plate, Fig. 7), *Cribrostomoides romanovae* (Bulynn.) (Plate, Fig. 13), and *Evolutinella grandis*. The accessory group includes *Cribrostomoides volubilis.*

Beds with Cribrostomoides concavoides

Member XXIII. The thickness is 27 m.

The unit was first proposed by Bulynnikova (1971) as beds with mass accumulations of the index species. The beds are composed of gray medium- to fine-grained sands with parallel bedding and thin clayey lentils. The lower boundary is arbitrarily drawn at the base of Member XXIII because no foraminifers were registered in underlying sediments.

The dominant group of the complex includes index species (Plate, Fig. 11), *Recurvoides nordvikensis* Marinov, sp. nov. (Plate, Fig. 8), and *Evolutinella grandis.* The accessory group includes *Recurvoides tigjanikus* and *Cribrostomoides romanovae.*

CORRELATION POTENTIAL OF BEDS WITH FORAMINIFERS AND THEIR STATUS

The section of the boreal Berriasian, lower Valanginian, and lower Hauterivian in the Nordvik Peninsula comprises six beds with foraminifers named after the following dominant species: *Trochamminoides emeljanzevi–Recurvoides praeobskiensis, Recurvoides romanovae, Recurvoides obskiensis, Evolutinella grandis, Recurvoides tigjanikus, Cribrostomoides concavoides.* Four of these units are distinguished for the first time. Beds with *Trochamminoides emeljanzevi* were first established by Basov (1972) as a unit corresponding to the boreal Jurassic–Cretaceous boundary interval. Beds with *Cribrostomoides concavoides* were defined by Bulynnikova (1971) in the Hauterivian of West Siberia (*Speetoniceras versicolor* Zone).

To estimate the correlation potential (lateral consistency) of beds with foraminifers distinguished in the Lower Neocomian of the Nordvik Peninsula, we studied distribution of foraminiferal species within the same stratigraphic interval in the sections of neighboring areas of East and West Siberia, and other regions, where deposits of the boreal and subboreal types are exposed.

In the northern areas of East Siberia, the nearest sections are located along the Tigyan-Yuryakh River, the eastern coast of the Anabar Bay, and in the Bol'shoi Begichev Island (Fig. 1). Unfortunately, the boreal Berriasian is missing from these sections, whereas the lower Valanginian and the lower (*Bojarkensis*) zone of the lower Hauterivian are well represented. The section along the Tigyan-Yuryakh River located 50 km west of the Nordvik Peninsula exhibits the boreal Berriasian–Valanginian boundary layers, all the molluscan zones of the lower Valanginian, and, probably, the upper Valanginian–boreal Hauterivian boundary strata. The section is composed of uniform dark gray to gray silty clay with horizons of carbonate and clayey-carbonate concretions. The integral thickness of the section is about 206 m (Bogomolov *et al.*, 1985). The analysis of foraminiferal distribution revealed four successive complexes and three units in the rank of beds with foramin-

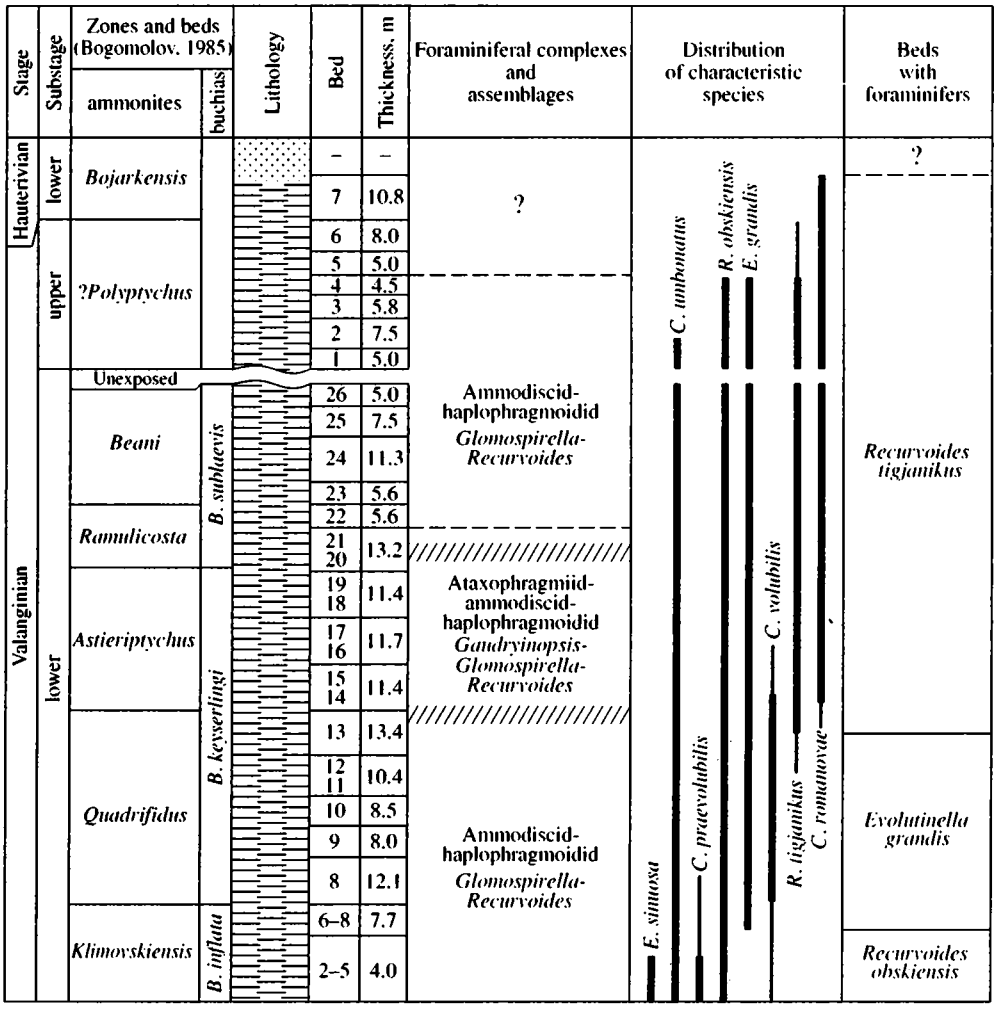


Fig. 4. Stratigraphic distribution of characteristic foraminiferal species, foraminiferal complexes, and beds with foraminifers in the section of the Valanginian and boreal lower Hauterivian along the Tigyan-Yuryakh River, northern East Siberia (symbols as in Fig. 3).

ifers analogous to *Recurvoides obskiensis*, *Evolutinella grandis*, and *Recurvoides tigjanikus* beds in the Valanginian of the Nordvik Peninsula (Fig. 4). The continuous exposure of the section made it possible to define, more precisely than in the Nordvik Peninsula, the boundaries of Beds with *Recurvoides tigjanikus* (Fig. 4): its lower boundary is close to the boundary between the *Quadrifidus* and *Astieriptychus* zones and the upper one is close to the Valanginian–Hauterivian boundary. The stratigraphic range of the Beds with *Evolutinella grandis* was also determined.

One of the best and well-studied lower Valanginian sections is located in the eastern coast of the Anabar Bay, 60 km southeast of the Nordvik Peninsula section (Fig. 1). Coastal scarps in this area are composed of dark gray silty clay with thin (0.3–0.4 m) interbeds of clayey limestone (the *Klimovskiensis*, *Quadrifidus*, and *Astieriptychus* ammonite zones) and with siltstone (the *Ramulicosta* Zone) and sandstone (the *Beani* Zone) members in the upper part. This stratigraphic interval corresponds to the *Buchia Inflata*, *B. keyserlingi*, and *B. sublaevis* zones. The total thickness of the considered section is less than 150 m (Bogomolov *et al.*, 1983). The section comprises three complexes and three units in the rank of beds with foraminifers (*Recurvoides obskiensis*, *Evolutinella grandis*, *Recurvoides tigjanikus*), the succession of which is approximately similar to that established in the Tigyan-Yuryakh section (Fig. 5).

The section on the Bol'shoi Begichev Island (Medvezhii Cape) is located several dozens of kilometers north of the Nordvik Peninsula section (Fig. 1) and, like in the latter, it is composed of the Valanginian dark gray silty clay (about 50 m thick) and boreal Hauterivian (the lower, *Bojarkensis* Zone) sandstone with rare clayey interbeds. The apparent thickness of the section is about 120 m. Foraminifers occur almost throughout the entire section, except for two intervals (Fig. 6). In this section, it was establish that the *Recurvoides tigjanikus* Beds correlate with the *Bojarkensis* Zone of the boreal Hauterivian and, consequently, the lower bound-

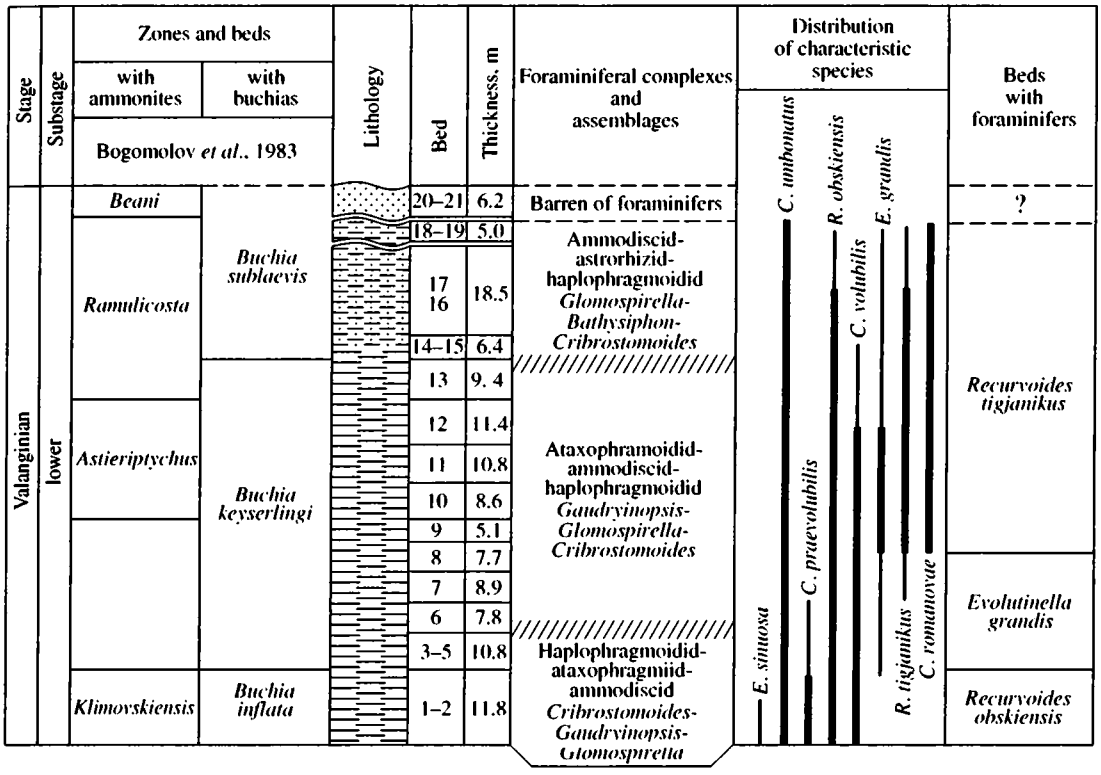


Fig. 5. Stratigraphic distribution of characteristic foraminiferal species, foraminiferal complexes, and beds with foraminifers in the lower Valanginian section in the eastern coast of the Anabar Bay, northern East Siberia (symbols as in Fig. 3).

ary of the Beds with *Cribrostomoides concavoides*, whose position in the Nordvik Peninsula section remains unclear, is located within the boreal lower Hauterivian (Fig. 6). According to data of Burdykina (1981), the section near the Medvezhii Cape (Bol'shoi Begichev Is.) includes only the upper Valanginian. She published one list of the late Valanginian mollusks collected from the lower clayey sequence more than 20 m thick. When describing ammonites, she used the letter designation of beds mentioning them as Beds C, E, and F. Unfortunately, neither stratigraphic position of beds nor their thickness are indicated in the paper. Inasmuch as we established the lower Valanginian Beds with *Recurvoides obskiensis* and Beds with *Evolutinella grandis* in the same interval of the section, it can be assumed that they correspond to the basal part of the section, i.e., to the Beds A and B not mentioned in the paper. In addition, according to data of M.A. Levchuk (field materials of 1973), the thickness of the clayey member approaches 50 m.

Correlation of beds with foraminifers in spatially close and lithologically similar sections of the Valanginian and boreal lower Hauterivian in the northern areas of East Siberia (the Nordvik Peninsula, eastern coast of the Anabar Bay, Tigyan-Yuryakh River, Bol'shoi Begichev Is.) showed that they form everywhere the same succession (Table 2). The Beds with *Recurvoides obskiensis*, *Evolutinella grandis*, *Recurvoides tigjanikus*, and *Cribrostomoides concavoides* are well traced. The succession of ammonite (Saks, 1972; Bogomolov, 1989) and buchia (Zakharov, 1981) zones established in the same sections allows an assumption that these beds have a stable stratigraphic position. The Beds with *Evolutinella grandis* in northern East Siberia closely correlate with the *Quadrifidus* ammonite zone. In two sections, they show contiguous patterns of the boundaries with underlying and overlying strata and, thus, can be considered as representing a foraminiferal zone.

To estimate the interregional correlation potential of beds with foraminifers established in the northern part of East Siberia, we studied the Lower Neocomian section in the Surgut area of West Siberia located almost 2000 km west–southwest of the Nordvik Peninsula (Fig. 1, point 6) using the core material from several boreholes (Malopyakutinskaya-543, Nasel'sk-563, Romanovo-140, Sugmut-423, Umsei-5, Yampino-8, Southern Pykuta-15 and 17, Nyudeyakha-300). It is noteworthy that foraminiferal complexes registered in these sections differ from those in northern Siberia. The peculiar composition of West Siberian complexes was repeatedly noted by previous researchers (Bulynnikova, 1973; Rodionova, 1976; Alekseeva *et al.*, 1982). Despite some shortages of the core material (spot sampling of the section and poor preservation), the West Siberion sections show the succession of beds with foraminifers identical to that in the northern areas of East

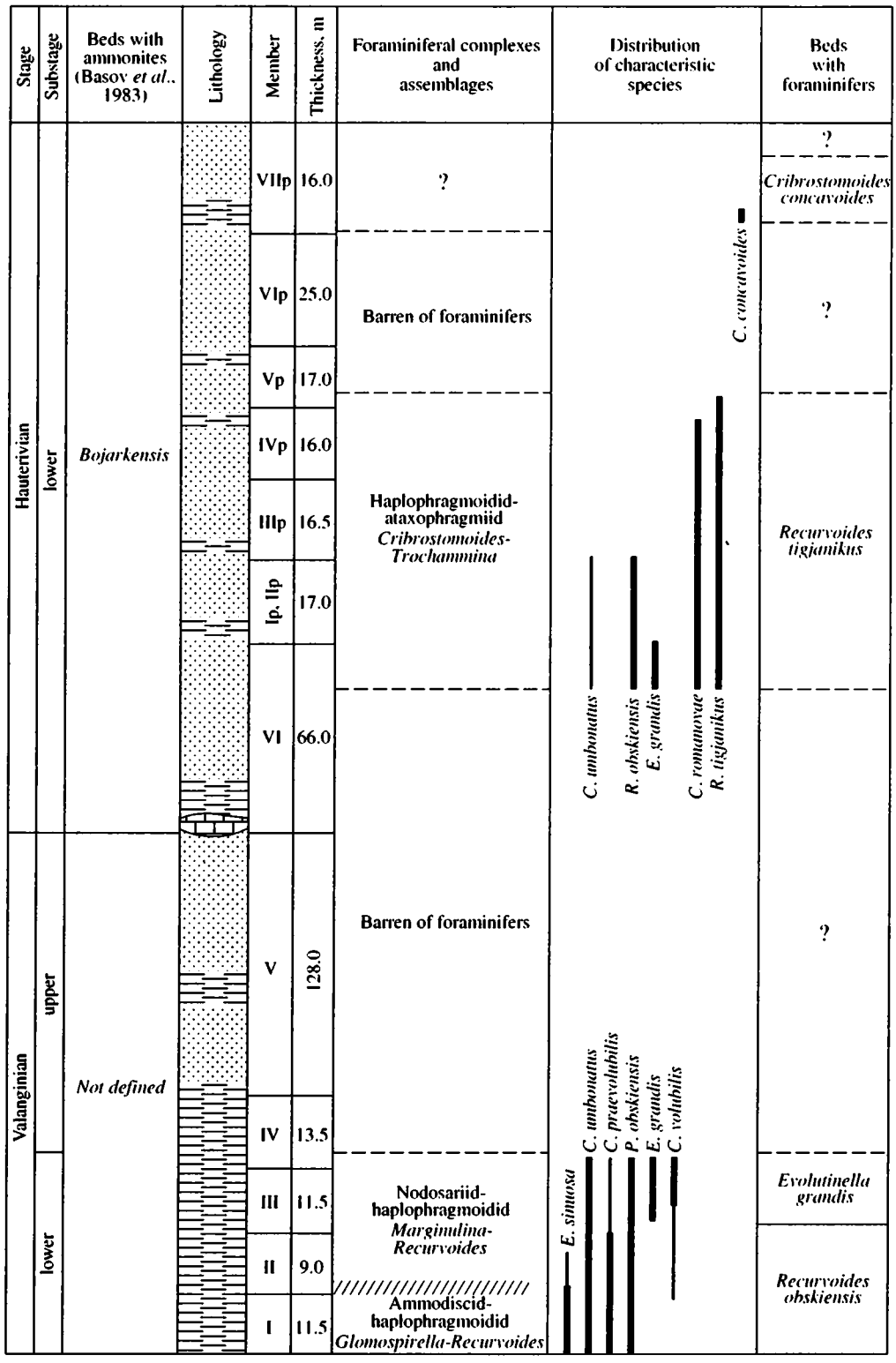


Fig. 6. Stratigraphic distribution of characteristic foraminiferal species, foraminiferal complexes, and beds with foraminifers in the lower Valanginian and boreal lower Hauterivian section on the Bol'shoi Begichev Island, northern East Siberia (symbols as in Fig. 3).

Table 2. Correlation scheme of beds with foraminifers in sections of the boreal lower Neocomian in northern East Siberia

Stage	Substage	Ammonite zones	Beds with foraminifers in particular sections of northern East Siberia				Foraminiferal zones and beds with foraminifers (standard)
			Nordvik Peninsula	Anabar River	Tigyan-Yuryakh River	Bol'shoi Begichev Is.	
Hauterivian	lower	*Bojarkensis*	*Concavoides*	Unsampled	Unsampled	*Concavoides*	*Concavoides*
			Foraminifers are missing			Foraminifers are missing	*Tigjanikus*
Valanginian	upper	*Kotschetkovi*	Unexposed	Unsampled	*Tigjanikus*	*Tigjanikus*	
		Bidichotomoides					
		Triplodiptychus				Foraminifers are missing	
	lower	*Beani*	*Tigjanikus*	*Tigjanikus*			
		Ramulicosta					
		Asteriptychus					
		Quadrifidus	?				
			Grandis	*Grandis*	*Grandis*	*Grandis*	*Grandis*
		Klimovskiensis	*Obskiensis*	*Obskiensis*	*Obskiensis*	*Obskiensis*	*Obskiensis*
Berriasian		*Tolli*	*Romanovae*	Unexposed	Unexposed		*Romanovae*
		Mesezhnikowi					
		Analogus					
		Kochi					
		Sibiricus					
Volgian	upper	*Chetae*	*Trochamminoides emeljanzevi*				*Trochamminoides emeljanzevi*
		Taimyrensis	*Recurvoides praeobskiensis*				*Recurvoides praeobskiensis*

Siberia, i.e., the succession of *Recurvoides romanovae, Recurvoides obskiensis, Evolutinella grandis, Recurvoides tigjanikus*, and *Cribrostomoides concavoides* beds (Fig. 7). The boreal Berriasian and early Valanginian ammonites coexisting with foraminifers in deposits of the above-mentioned boreholes allow them to be considered as stratigraphic analogues of synonymous beds in northern Siberia. Thus, the Beds with *Recurvoides romanovae, Recurvoides obskiensis, Evolutinella grandis, Recurvoides tigjanikus*, and *Cribrostomoides concavoides* can be considered as representing regional zones.

The correlation potential of the proposed zonal scale is probably not limited by East and West Siberia. One can assume that some zones or their reliably substantiated stratigraphic analogues can also be recorded beyond the Siberian region in areas of the boreal and subboreal deposits. Basov was first to perform interregional correlation of beds with foraminifers for the boreal Berriasian (Basov, 1968), Valanginian and Hauterivian (Basov *et al.*, 1989). Already in his earlier work, he noted "an extreme uniformity of the late Volgian complex of agglutinated foraminifers (*Ammodiscus veteranus* and *Evolutinella emeljanzevi* beds), which is sustained throughout the vast region of northern Siberia... and comparable only with the uniformity of modern complexes in the deep areas of the World Ocean" (Basov, 1968, p. 109). The beds with foraminifers in the lower part of the boreal Berriasian are correlative through the northern Siberia, Pechora plate, and southern Barents Sea basin: (*Trochammina rosaceaformis* and *Gaudryina gerkei, Kutsevella praegoodlandensis* and *Lenticulina sossipatrovae, Recurvoides obskiensis* and *Orientalia(?) baccula* beds). Based on foraminiferal complexes, the lower Valanginian and Hauterivian deposits were traced through these regions (Basov *et al.*, 1989; scheme).

Our data confirm the possibility of interregional correlation of the Lower Neocomian relatively deep marine deposits at the stage and substage level (Table 3). They

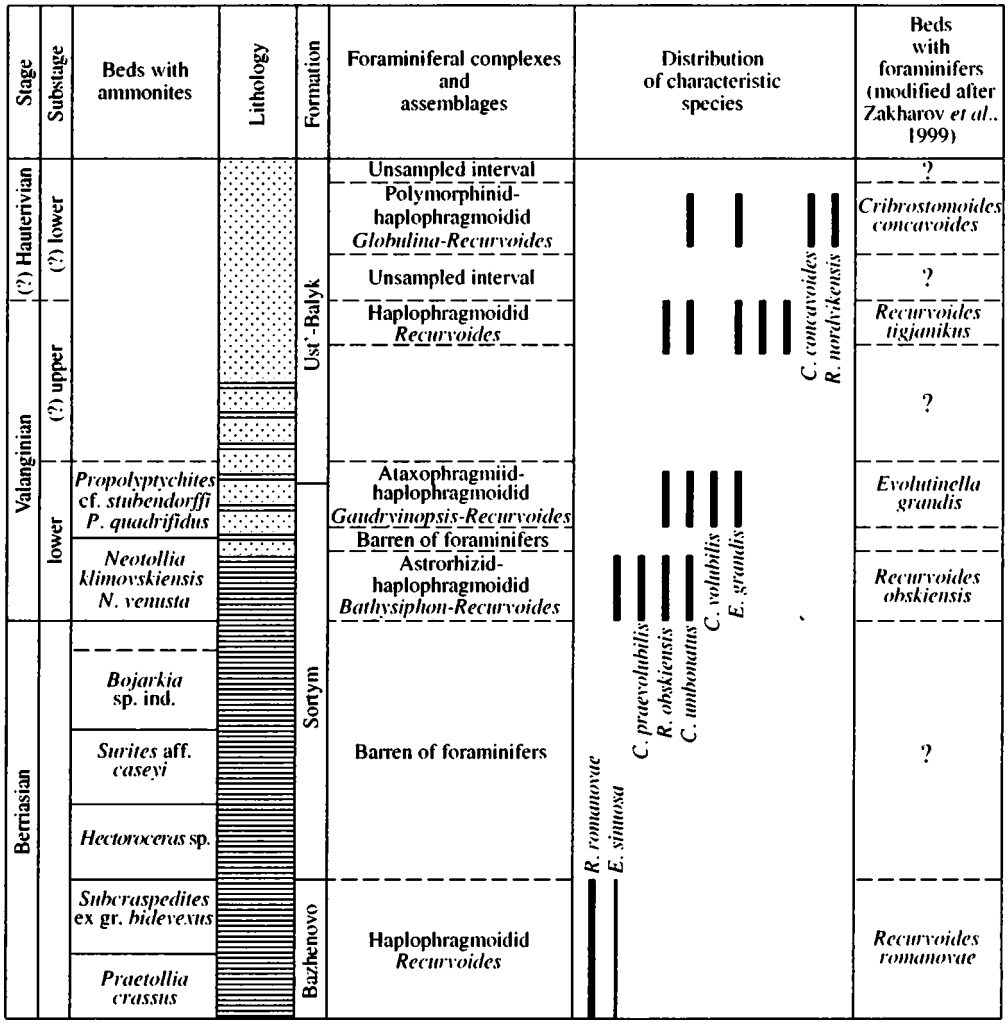


Fig. 7. Stratigraphic distribution of characteristic foraminiferal species, foraminiferal complexes, and beds with foraminifers in the integral section of the Neocomian in the Surgut area of West Siberia (symbols as in Fig. 3).

also support the reliable correlation of beds with foraminifers at the top of the upper Volgian Substage throughout the entire northern part of Siberia, as it was previously noted by Basov. The *Recurvoides romanovae* Zone is traced at the base of the boreal Berriasian of the Barents Sea plate and in Spitsbergen (Basov *et al.*, 1989; Nagy *et al.*, 1990). *Kutsevella praegoodlandensis*, one of the characteristic forms of this north Siberian zone is a dominant species of the synonymous beds in the lower part of the boreal Berriasian in the Pechora plate (Azbel' and Grigelis, 1991).

The change in composition of the dominant haplophragmoidid and nodosariid group in the lower Valanginian, namely the extinction of *Cribrostomoides volubilis* (Rom.), *Lenticulina lideri* (Rom.), and *L. variabilis* Rom. with simultaneous appearance of *L. neocomiana* (Rom.), correlates the lower boundary of the north Siberian *Recurvoides tigjanikus* Zone with the lower boundary of the *"Kutsevella" pseudogoodlandensis–Lenticulina subcrassa* Zone of the Pechora plate. We correlate the Beds with *Cribrostomoides concavoides* (lower Hauterivian) with the *Reophax torus–Globulina praelacrima–Astacolus assurgensis* Zone in the North Caspian depression based on the presence of *C. concavoides* in the latter (Plate III). The potential of foraminifers for interregional correlation is not exhausted by the above-mentioned stratigraphic intervals. The Nordvik Peninsula section contains *Lenticulina* ex gr. *macrodisca* (Reuss) and *Epistomina* ex gr. *caracolla* (Roem), the species characteristic of the lower Valanginian in the Boreal-Atlantic zoochore and assuming possibility to distinguish other reference levels. It is also important that taxons from different regions of the boreal realm are identified by the same researcher.

It should be emphasized once again that the proposed foraminifer-based zonal scale is effective first of all for correlation of marine clayey and silty–clayey Lower Neocomian deposits of the boreal type. Simultaneously, it is not so effective for correlation of other

Table 3. Foraminifer-based correlation of the Neocomian in the boreal areas

Stage	Substage	Ammonite zones	East Siberia proposed scheme	West Siberia, Surgut area (Zakharov *et al.*, 1999 modified)	North Caspian depression (Azbel' and Grigelis, 1991)	Pechora plate (Azbel' and Grigelis, 1991)	South Barents Sea plate (Basov *et al.*, 1989)	Spitsbergen Is. (Nagy *et al.*, 1990)
							This work	
Hauterivian	lower	*Bojarkensis*	*Cribrostomoides concavoides*	*Cribrostomoides concavoides*	*Reophax torus – Globulina praelacrima obessa – A. assurgensis*	*Kutsevella pseudogomensis – Hoeglundina caracolla nordensis*	*Lenticulina macrodisca – Trocholina* sp.	
Valanginian	upper	*Kotschetkovi*	*Recurvoides tigjanikus*	*Recurvoides tigjanikus*	*Ammobaculites prosper – Globulina fusina*			
		Bidichotomoides						
		Triplodiptychus						
	lower	*Beani*			*"Kutsevella" pseudogoodlandensis Lenticulina subcrassa*	*Reophax minutissima – Lenticulina eichenbergi*		*Glomospira* spp. *Glomospirella* spp.
		Ramulicosta						
		Asteriptychus						
		Quadrifidus						
		Klimovskiensis	*Evolutinella grandis*	*Evolutinella grandis*	*Recurvoides excellens – L. lideri*	*Recurvoides excellens – Kutsevella pseudogoodlandensis*		
Berriasian		*Tolli*	*Recurvoides obskiensis*	*Recurvoides obskiensis*	*A. granulum – L. andromedovae – L. dzhamyschensis*			*Gaudryina* aff. *milleri*
		Mesezhnikowi	*Recurvoides romanovae*	*Recurvoides romanovae*	*Recurvoides valanginicus – R. embensis*	*Kutsevella pseudogoodlandensis – Lenticulina* gr. *sossipatrovae*	*Recurvoides romanovae – Orientalia* (?) *baccula*	*Recurvoides romanovae*
		Analogus						
		Kochi						
		Sibiricus						
Volgian	upper	*Chetae*	*Trochamminoides emeljanzevi – Recurvoides praeobskiensis*	?		*Bullopora vivejae – Ammobaculites diligens*	*Ammodiscus veteranus – Trochamminoides emeljanzevi*	*Trochammina* aff. *abrupta*
		Taimyrensis						

facies. For instance, the Lower Neocomian coastal shallow-water deposits are subdivided using the succession of the secretory foraminiferal groups in the section (Basov and Ivanova, 1972; Bulynnikova, 1981; Fedorova, 1993). This zonation has none of zones in common with our scale proposed for the deposits of the Nordvik Peninsula (Anabar Bay) accumulated in relatively deep sea settings. Thus, parallel scales should be elaborated for correlation of different-facies sections.

CONCLUSION

The performed micropaleontological study of most complete boreal-type sections of the Berriasian, Valanginian, and Hauterivian in the Anabar Bay (Laptev Sea) revealed the diverse complexes mainly consisting of agglutinated foraminifers. They are dominated (75–100%) by representatives of the family Haplophragmoididae Maync, 1952 (genera *Recurvoides, Evolutinella, Cribrostomoides*, and *Trochammminoides*). The comprehensive study of foraminifers from these genera allowed the volume of species and their stratigraphic intervals to be specified. Evolutionary–morphological transformations of species belonging to three first genera served as the basis for elaboration of the foraminiferal zonal scale based on the Lower Neocomian sections of East Siberia. The complete succession of six units in the rank of beds with foraminifers is established in the most appropriate section of the Nordvik Peninsula. Fragments of this succession are registered in spatially close (within 100 km) and lithologically similar sections in the Tigyan-Yuryakh River, Anabar Bay eastern coast, and Bol'shoi Begichev Is. The same succession of all beds with foraminifers established in the Lower Neocomian of northern East Siberia are recorded in several sections drilled by boreholes in the Surgut area of West Siberia located about 2000 km west-southwest of the Nordvik Peninsula. This is a good basis for ranking these units as foraminiferal zones. The concurrent ammonites and buchias in section of both East and West Siberia allowed the stratigraphic range and geological age of these units to be determined. The foraminiferal scale ranging from the upper part of the upper Volgian Substage to the base of the boreal lower Hauterivian and including *Trochammminoides emeljanzevi–Recurvoides praeobskiensis, Recurvoides romanovae, Recurvoides obskiensis, Evolutinella grandis, Recurvoides tigjanikus*, and *Cribrostomoides concavoides* zones is proposed as a standard for the relatively deep-water deposits of the boreal type. The complexes include species reported from areas beyond Siberia, e.g., from the Pechora and Barents Sea plates, as well as from the North Caspian depression, that is favorable for interregional correlation at the stage and substage level.

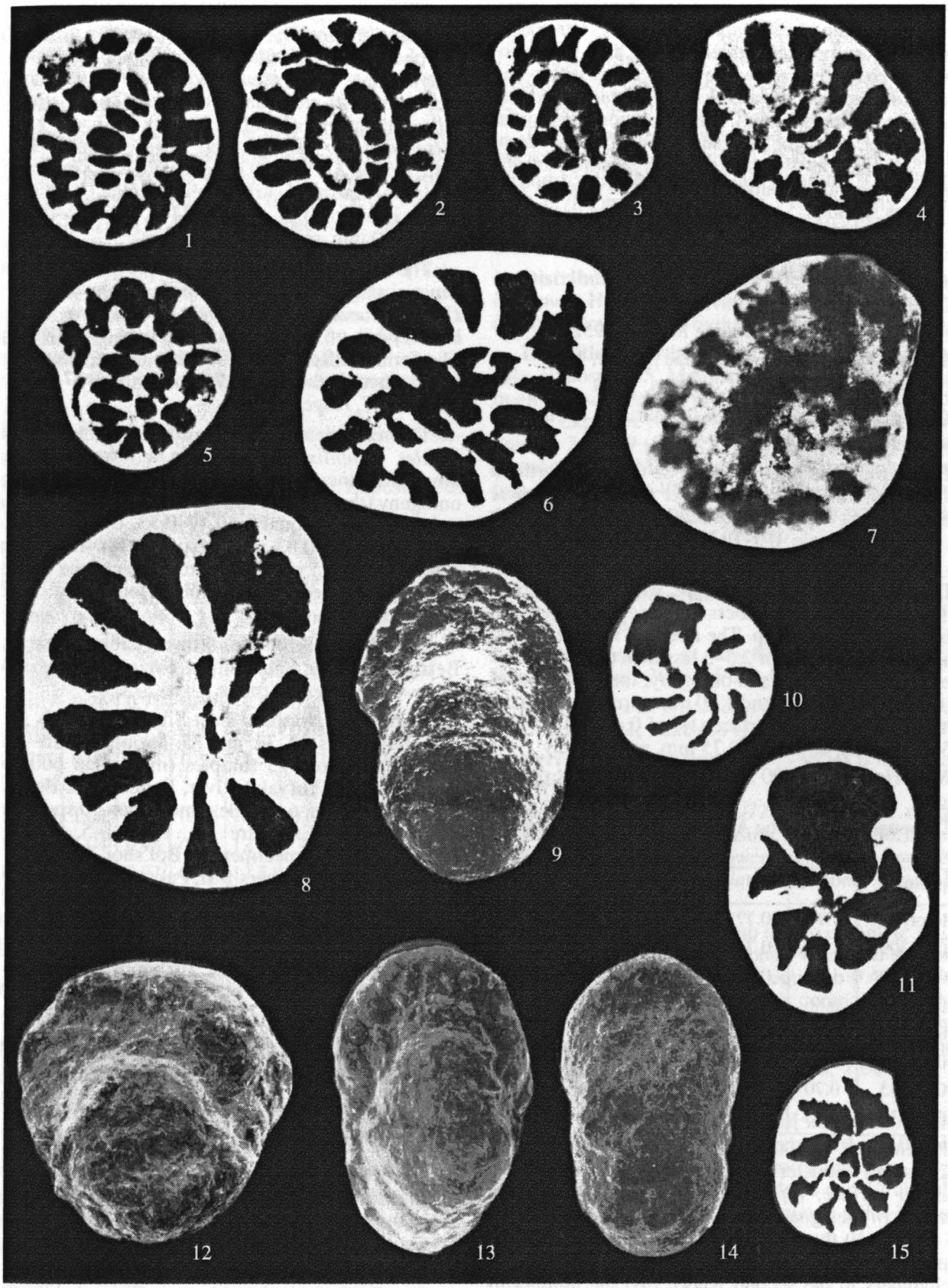
Based on peculiarities of composition and distribution of foraminifers, the relatively autonomous groupings of taxons (foraminiferal complexes) are discriminated. The stratigraphic interval from the Jurassic–Cretaceous boundary layers to the boreal lower Hauterivian comprises six successive complexes. In our opinion, these complexes reflect the life-time transformations of taxa assemblages, whose compositional and structural changes were controlled by the integral environmental changes related, in particular, to the general shoaling of the basin and phylogenetic radiation.

Foraminifers from the Lower Cretaceous (Berriasian, Valanginian, Hauterivian) of northern East Siberia.

All pictured specimens are stored at the Central Siberian Geological–Mineralogical Museum (CSGM), collection 1072.

Microphotographs 1–8, 10, 11, 15 are shot in the immersion liquid, and 9, 12–14, under the scanning electron microscope.

(1–3) *Recurvoides praeobskiensis* Dain et Bulynnikova, 1986. (1) specimen 1072/283, side view, ×56; northern East Siberia, Nordvik Peninsula, Exposure 33, Member X, Sample 4-32; Lower Cretaceous, Berriasian, *Chetaites sibiricus* Zone, Paksa Formation; (2) specimen 1072/285, side view, ×56; (3) specimen 1072/284, side view, ×56; locality of specimens in Figs. 2 and 3 the same as for specimen 1072/283. (4, 5) *Recurvoides romanovae* Putrja, 1967. (4) specimen 1072/286, side view, ×60; northern East Siberia, Nordvik Peninsula, Exposure 32, Member XII, Sample 15-33; Lower Cretaceous, Berriasian, *Hectoroceras kochi* Zone, Paksa Formation; (5) specimen 1072/287, side view, ×51; the same locality. (6) *Recurvoides obskiensis* Romanova, 1960. Specimen 1072/290, side view, ×60; northern East Siberia, Nordvik Peninsula, Exposure 33, Member XVII, Sample 29-32; Lower Cretaceous, lower Valanginian, *Neotollia klimovskiensis* Zone, Paksa Formation. (7) *Recurvoides tigjanikus* Marinov, s. nov. Specimen 1072/270, holotype, side view, ×58; northern East Siberia, Nordvik Peninsula, Exposure 35, Member XIX, Sample 35-35-1; Lower Cretaceous, lower Valanginian, *Euryptychites astieriptychus* Zone, Paksa Formation. (8) *Recurvoides nordvikensis* Marinov, sp. nov. Specimen 1072/295, holotype, side view, ×57; northern East Siberia, Nordvik Peninsula, Exposure 36, Member XXIII, Sample 2-36-89; Lower Cretaceous, lower Hauterivian, *Homolsomites bojarkensis* Zone, Tigyan Formation. (9, 10) *Cribrostomoides praevolubilis* Marinov, sp. nov. (9) holotype, specimen 1072/308, apertural view, ×50; northern East Siberia, Anabar River, Exposure 1A, Bed 1, Sample 0-1-1, 1.5 m above the base; Lower Cretaceous, lower Valanginian, *Neotollia klimovskiensis* Zone, Paksa Formation; (10) specimen 1072/312, side view, ×38; the same locality. (11) *Cribrostomoides concavoides* Bulynnikova. Specimen 1072/399, side view, ×40; northern East Siberia, Nordvik Peninsula, Exposure 36, Member XXII, Sample 2-36-89, 3.6 m above the base; Lower Cretaceous, lower Hauterivian, *Homolsomites bojarkensis* Zone, Tigyan Formation. (12) *Cribrostomoides volubilis* (Romanova), 1960. Specimen 1072/324, apertural view, ×44; northern East Siberia, Anabar River, Exposure 1A, Bed 1, Sample 0-1-4, 7.5 m above the base; Lower Cretaceous, lower Valanginian, *Neotollia klimovskiensis* Zone, Paksa Formation. (13) *Cribrostomoides romanovae* Bulynnikova, 1971. Specimen 1072/382, apertural view, ×50; northern East Siberia, Anabar River, Exposure 1A, Bed 14, Sample 0-24-37, 0.5 m above the base; Lower Cretaceous, lower Valanginian, *Sibirites ramulicosta* Zone, Paksa Formation. (14, 15) *Cribrostomoides umbonatus* (Romanova), 1955. (14) specimen 1072/411, apertural view, ×52; West Siberia, Surgut area, Borehole Yuzhnopyakutinskaya-17, depth of 2737 m, Sample 17-13; Lower Cretaceous, lower Valanginian, *Neotollia klimovskiensis* Zone, Sortym Formation; (15) specimen 1072/400, side view, ×60; northern East Siberia, Anabar River, Exposure 1A, Bed 8, Sample 0-14-18, 5.5 m above the base; Lower Cretaceous, lower Valanginian, *Propolyptychites quadrifidus* Zone, Paksa Formation.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Transitions between complexes (assemblages) correspond to certain stratigraphic intervals (stratoecotones). The complexes (assemblages and stratoecotones) are characterized by the stable composition and structure in the case of lateral facies stability and can serve as an additional proxy for correlation of monofacies sections. Nonetheless, successions of the complexes, as well as the stratigraphic position of the boundary intervals (stratoecotons), differ even in spatially close sections.

TAXONOMIC DESCRIPTION

Order LITUOLIDA Blainville, 1825

Family Haplophragmoididae Maync, 1952

Subfamily Haplophragmoidinae Maync, 1952

Genus *Cribrostomoides* Cushman, 1910

Cribrostomoides praevolubilis Marinov, sp. nov.

Plate, Figs. 9, 10.

Holotype: Specimen 1072-308, CSGM; northern East Siberia, Anabar River, Lower Cretaceous, lower Valanginian, *Neotollia klimovskiensis* Zone, Exposure 1A, Bed 1, Sample 0-1-1, Paksa Formation, Plate, Fig. 9.

Diagnosis. The test is involute, with 7 chambers in the first whorl and 8 chambers in the second whorl. An umbo is narrow and deep. The aperture surface is low; its height is by a factor of 2.5–3 less than the width. The latter regularly increases in ontogeny; the test diameter (D) of 0.60, 0.70, 0.80, and 1.00 mm corresponds to the width of the apertural surface (H) of 0.43–0.45, 0.50–0.55, 0.55–0.60, and 0.70–0.75 mm, respectively.

Material: About 200 specimens of different preservation.

Dimensions, mm, the Anabar River, Bed 1, Sample 0-1-2.

Specimen	*D*	*H*	*n*	*N*	*dp*	D_1
Holotype	1.13	0.77	8			
1072-309	1.00	0.73				
1073-310	1.00	0.67				
1072-312	0.86		7	12		
1072-319	0.80	0.55				
1072-313	0.79		8	11	0.12	0.57
1072-315	0.70		7	10	0.10	0.60
1072-334	0.55	0.40				

Hereinafter: (*D*) the large diameter of the test; (*d*) the small diameter of the test; (*H*) the width of the apertural surface; (*dp*) the diameter of the primary chamber; (*n*) designates the number of chambers in the last whorl; (*N*) the total number of chambers; (n_1) the number of chambers in the first whorl; (n_2) the number of chambers in the second whorl; (n_3) the number of chambers in the third whorl; (D_1) the diameter of the first whorl.

Variability: see diagnosis and dimensions.

Comparison. The considered species differs from morphologically similar *Cribrostomoides romanovae* Bulynnikova in the greater width of the apertural surface when tests are equal in diameter. The *C. praevolubilis* test diameter (D) of 0.60, 0.70, 0.80, and 1.00 mm corresponds to the apertural surface height of 0.43–0.45, 0.50–0.55, 0.55–0.60, and 0.70–0.75 mm, respectively (the apertural surface height of the *C. romanovae* test is equal to 0.37–0.40, 0.44–0.48, 0.52–0.55, and 0.65–0.70 mm, respectively).

The height of the apertural surface in the same ontogenetic stage of *Cribrostomoides praevolubilis* and *Cribrostomoides concavoides* Bulynnikova from the Hauterivian of Siberia (Bulynnikova, 1971) is equal. The former differs from the latter in a greater number of chambers in the first and second whorls (7 and 8 versus 6 and 7, respectively).

The considered species differs from *Cribrostomoides volubilis* Romanova in a lower rate of the dimension increase in the apertural surface during ontogeny (the width of the apertural surface of *C. praevolubilis* test is equal to 0.47–0.53, 0.55–0.60, 0.62–0.70, and 0.78–0.83 mm, respectively). It also has a deeper umbo (*C. volubilis* virtually lacks the umbilical deep and inner edges of chambers join in the center of the lateral side).

Distribution: Siberia, Lower Cretaceous, boreal Berriasian–lower Valanginian, *Surites analogus–Neotollia klimovskiensis* zones.

Localities: Northern East Siberia, Nordvik Peninsula, Exposures 32, 33, and 35, Members XIII–XVIII, Paksa Formation, 15 samples (more than 600 specimens); Tigyan-Yuryakh River, Exposure 1, Beds 1–3, Paksa Formation, 6 samples (more than 50 specimens); Anabar River, Exposure 1A, Beds 1–5, 8 samples (more than 80 specimens); Bol'shoi Begichev Is., Exposure 504, Members I–II, Paksa Formation, 9 samples (125 specimens); West Siberia, Surgut area, Sortym Formation, Borehole Nassel'sk-563, Interval of 2660–2667 m, Borehole Western Nadym-70, Interval of 2632–2645 m, Borehole Yuzhnopyakutinskaya-17, Interval of 2734–2738 m, 12 samples (more than 50 specimens).

Subfamily Recurvoidinae Alekseitchik, 1973

Genus *Recurvoides* Earland, 1934

Recurvoides tigjanikus Marinov, sp. nov.

Plate, Fig. 7

Recurvoides sinuosus: Myatluk, 1988, Plate 4, Fig. 10; Plate 5, Figs. 1, 2.

Recurvoides princeps: Myatluk, 1988 (partly), Plate 5, Figs. 3, 5.

Derivation of the name. The species is named after the Tigyan-Yuryakh River.

Holotype: Specimen 1072-270, CSGM; northern East Siberia, Nordvik Peninsula, Exposure 35, Member XIX, Sample 35-35-1; Lower Cretaceous, lower Valanginian, *Euryptychites astieriptychus* Zone, Paksa Formation, Plate, Fig. 7.

Diagnosis. The width of the first, second, and third whorls in the megaspheric generation is 0.40, 0.65–0.70, and 1.10–1.20 mm, respectively. Tests consisting of 10, 20, and 30 chambers are 0.40–0.45, 0.75–0.85, and 1.10–1.20 mm in diameter, respectively. Tests with 11 and 12 chambers in the last whorl are 0.85–0.90 and 0.90–1.00 mm in diameter, respectively (Plate, Fig. 12). In the test of megaspheric generation, the width of the second whorl is 0.50–0.60 mm. Tests with 10 and 20 chambers are to 0.35 and 0.60–0.65 mm in size, respectively, and those with 10 and 13 chambers in the last whorl are to 0.45–0.50 and 0.70–0.75 mm across.

Material. About 100 specimens of different preservation.

Dimensions, mm. Nordvik Peninsula, Exposure 35, Member XIX, Sample 35-35-1.

Megaspheric generation

Specimen	*D*	*d*	*H*	*n*	*dp*	*N*	n_1	n_2	n_3
1072-105	0.44	0.38	0.21	8	0.06	11	6		
1072-268	0.64	0.55	0.23	9					
1072-269	0.68	0.60	0.23	10	0.07	17	7	10	
1072-107	0.76	0.71	0.30	10.5	0.08	19	6	9	
Holotype	0.95	0.73	0.26	11	0.08	23	6	10	
1072-271	0.97	0.77	0.30	11	0.07	25	7	9	
1072-293	0.98			11					
1072-110	1.02	0.90	0.41	12	0.08				
1072-273	1.04	0.98	0.35	12					
1072-112	1.10	0.97	0.41	12.5	0.06	29	6	9	12

Microspheric generation

Specimen	*D*	*d*	*H*	*n*	*dp*	*N*	n_1	n_2
1072-294	0.46			9.5				
1072-115	0.48	0.47	0.17	10	0.06	15	6	
1072-116	0.54	0.50	0.17	11				
1072-118	0.60	0.54	0.18	12				
1072-120	0.75	0.65	0.28	12.5				
1072-122	0.86	0.70	0.29	14	0.07			

Variability. Ontogeny is characterized by the growing degree of test enveloping (from involute to semievolute), by increasing number of chambers in the last whorl, and by the apertural surface widening (see diagnosis and dimensions).

Comparison. The considered species differs from *Recurvoides obskiensis* Rom. in a higher rate of the whorl height increase. The diameter of the first, second, and third whorls in the megaspheric generation of *R. tigjanikus* is equal to 0.40, 0.65–0.70, and 1.10–1.20 mm, respectively (these parameters for *R. obskiensis* are equal to 0.65–0.70, 0.70–0.80, and 0.80–0.90 mm, respectively).

The diameter of the second whorl in tests of the microspheric generation is 0.50–0.60 mm. Tests with 10 and 13 chambers in the last whorl are 0.45–0.50 and 0.70–0.75 mm in diameter, respectively (similar parameters for *R. obskiensis* are 0.40–0.45 and 0.60–0.65 mm, respectively).

Distribution: Siberia, Lower Cretaceous, Valanginian–lower Hauterivian; North Caspian depression, Valanginian–lower Hauterivian.

Localities: Northern East Siberia, Nordvik Peninsula, Exposure 35, Members XIX and XX, Paksa Formation, 9 samples (more than 40 well-preserved specimens); Exposure 36, Member XXIII, Paksa Formation, Sample 2-36-89 (2 specimens); Bol'shoi Begichev Is., Exposure 502, Members VI, Ip–IVp, Tigyan Formation, 12 samples (40 specimens); West Siberia, Surgut area, Borehole Yampino-8, Sortym Formation, Interval of 2727–2780 m (30 specimens).

Recurvoides nordvikensis Marinov, sp. nov.

Plate, Fig. 8.

Recurvoides ex gr. *stschekuriensis*: Flower and Braun, 1993, pp. 30–31, Plate 4, Figs. 10–12.

Recurvoides ex gr. *canningensis*: Flower and Braun, 1993, pp. 30–31, Plate 4, Figs. 22–26.

Derivation of the name. The species is named after the Nordvik Peninsula.

Holotype: Specimen 1072/270, CSGM; northern East Siberia, Nordvik Peninsula, Exposure 36, Member XXIII, Sample 2-36-89; Lower Cretaceous, lower Hauterivian, *Homolsomites bojarkensis* Zone, Tigyan Formation, Plate, Fig. 8.

Diagnosis. The test has up to two complete whorls. The width of the first and second whorls in the test of the megaspheric generation is equal to 0.40–0.45 and 0.75–0.80 mm, respectively. Tests composed of 10, 20, and 25 chambers are 0.55, 0.90–95, and 1.20 mm in diameter, respectively; tests with 10, 11, and 12 chambers in the last whorl are 0.90–1.00, 1.00–1.10, and 1.20 mm in diameter, respectively.

The width of the second whorl in the microspheric generation is 0.70 mm. Tests composed of 10 and 20 chambers are 0.45 and 0.80 mm in diameter, respectively. The diameter of tests with 10 and 12 chambers in the last whorl is 0.70–0.80 mm and 0.90–1.00 mm, respectively.

Material: about 60 specimens of different preservation.

Dimensions, mm. Nordvik Peninsula, Exposure 36, Member XXIII, Sample 2-36-89.

Megaspheric generation

Specimen	*D*	*d*	*H*	*n*	*dp*	*N*	n_1	n_2
1072-228	0.40	0.38	0.17	7	0.09	8	7	
1072-229	0.47	0.43	0.19	6	0.07	9	6	
1072-231	0.55	0.50	0.22	7	0.07	10	6	
1072-233	0.57	0.50	0.23	8	0.07	11	7	
1072-236	0.61	0.58	0.27	8		13	6	
1072-237	0.76	0.70	0.35	9	0.07	16	7	9
1072-238	0.97	0.90	0.30	10.5	0.08	21	7	9
1072-240	1.05	0.96	0.36	11	0.085	22	7	9
1072-296	1.06			11				
1072-241	1.10	0.98	0.43	11.5		22	6	9
1072-243	1.20	1.03	0.52	11	0.10	24	7	9
Holotype	1.20			12				

Microspheric generation

Specimen	*D*	*d*	*H*	*n*	*dp*	*N*	n_1	n_2
1072-244	0.98	0.87	0.36	12.5		23		
1072-297	0.73			9				
1072-245	0.70	0.60	0.32	9	0.09	17	7	9
1072-247	0.48	0.40	0.16	8	0.054	12		
1072-249	0.40	0.36	0.25	6.5	0.08	9	6	

Variability. Ontogeny is characterized by growth in the degree of the test enveloping (test with a single complete whorl is involute, and that with two whorls is involute at one side and partly evolute at the other), in the number of last whorl chambers, and in the width of apertural surface (see diagnosis and dimensions).

Comparison. The considered species differs from *Recurvoides tigjanikus* sp. nov. in a significantly higher rate of the whorl diameter increase. In the tests of microspheric generation, the first and second whorls are 0.40–0.45 and 0.75–0.80 mm in diameter, respectively (analogous parameters of *R. tigjanicus* are 0.40 and 0.65–0.70 mm, respectively). Tests with 10, 11, and 12 chambers are 0.90–1.00, 1.00–1.10, and 1.20 mm in diameter, respectively (the same parameters for *R. tigjanikus* are equal to 075–0.80, 0.85–0.90, and 0.90–1.00 mm, respectively).

The width of the second whorl in tests of the microspheric generation is 0.70 mm (that in *R. tigjanikus* is 0.05–0.60 mm). Tests with 10 chambers in the last whorl are 0.70 mm in diameter, those with 12 chambers, 0.90–1.00 mm in diameter (in *R. tigjanikus*, 0.40–0.50 and 0.60–0.65 mm, respectively).

Distribution: Siberia, Lower Cretaceous, lower Hauterivian, *Homolsomites bojarkensis* Zone; Arctic Canada, Hauterivian–Barremian.

Localities: northern East Siberia, Nordvik Peninsula, Exposure 36, Member XXIII, Tigyan Formation, Sample 2-36-8, 3-36-89 (more than 40 specimens of different preservation); Borehole Umsei-5, Ust'-Balyk Formation, Interval of 2673–2680 m (12 specimens).

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Infrazonal Ammonite Scale for the Upper Bathonian–Lower Callovian of Central Russia

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Abstract—The regional infrazonal scale for the upper Bathonian–lower Callovian is elaborated on the basis of successive ammonite assemblages in some Middle Jurassic sections of Central Russia. Four zones and 13 biohorizons, most of which are well correlative to the standard West European units, are distinguished in the studied stratigraphic interval. The *Infimum* Zone including the *C. infimum* and *C.* cf./aff. *infimum* biohorizons is the lowermost unit of the scale. According to its stratigraphic position below the *Elatmae* Zone, the above unit approximately corresponds to the *Discus* Zone and probably the upper part of the *Orbis* Zone of the standard upper Bathonian scale. The succeeding *Elatmae* Zone is subdivided into the *M. jacquoti, C. elatmae, C. tschernyschewi, C. surensis, C. subpatruus,* and *Ch. saratovensis* biohorizons. Due to some correlative stratigraphic levels, this zone is considered to be analogous to the basal Callovian *Herveyi* Zone of the standard scale. The *Koenigi* Zone including the *K. densicostatus, K. curtilobus,* and *K. trichophorus* biohorizons is an equivalent of the synonymous zone of the standard scale. The lower Callovian succession is completed by the *Calloviense* Zone comprising the *S. calloviense* and *S. enodatum* biohorizons. It is also analogous to the synonymous standard zone.

Key words: upper Bathonian, lower Callovian, ammonites, biohorizons, stratigraphy, Central Russia.

The terminal Bathonian–initial Callovian time of the Earth history is marked by an extensive sea transgression in the Northern hemisphere. As a result, the Russian platform turned into the East European sea basin, the central part of which could be termed the Central Russia sea. Being connected with the Arctic (boreal) and Tethyan (tropical) sea basins, the sea was favorable for migration of faunas of different biogeographic genesis. For this reason, sediments and fossils of the Central Russia sea are extremely important objects of stratigraphic and paleontological studies. On the one hand, they make it possible to correlate stratigraphic schemes for different regions. On the other hand, they represent perfect material to study evolution of biotas with heterogeneous components.

In spite of extensive list of publications on the Middle Jurassic of the Russian platform, which appeared since the last century, the investigation level of Bathonian–Callovian deposits in Central Russia is still lower than that in many other regions. Distribution and taxonomic composition of some stratigraphically important groups of ammonites remain here disputable or unclear. Until the recent time, the boreal Bathonian marine deposits have not been known to occur in this region and special investigations have not been carried out (Gulyaev and Kiselev, 1999; Gulyaev, 1999).

Accordingly, the main purpose of this work is to define vertical ranges and evolutionary links of the late Bathonian–early Callovian ammonites of Central Russia in order to elaborate a refined stratigraphic scale, which could be useful for thorough phylogenic, paleoecological, and paleogeographic investigations.

The study material was obtained during the field works in 1991–1998. The collection of fossils is stored in the Chair of Paleontology of the Moscow State University.

DESCRIPTION OF SECTIONS

The upper Bathonian–lower Callovian stratigraphy and ammonites of Central Russia were studied in the following sites of the Nizhni Novgorod, Kostroma, Ryazan, Moscow, and Yaroslavl areas (Fig. 1): (1) the Prosek-Isady section (the Nizhnii Novgorod area, a quarry in the northwestern outskirts of the Prosek Village and a series of outcrops at the right bank of Volga between the Prosek and Isady villages); (2) the Uzhovka section (the Nizhni Novgorod area, a quarry in the northwestern outskirts of the Uzhovka Settlement); (3) the Akatovo section (the Kostroma area, an outcrop at the right bank of the Unzha River, 1 km downstream from the Akatovo Village); (4) the Pezhenga section (the Kostroma area, an outcrop at the left bank of the Unzha River downstream from the Pezhenga River mouth); (5) the Manturovo–Znamenka section (the Kostroma area, the outcrops at the right bank of the Unzha River near the town of Manturovo and Znamenka Village); (6) the Ivkino section (the Kostroma area, an outcrop at the right bank of the

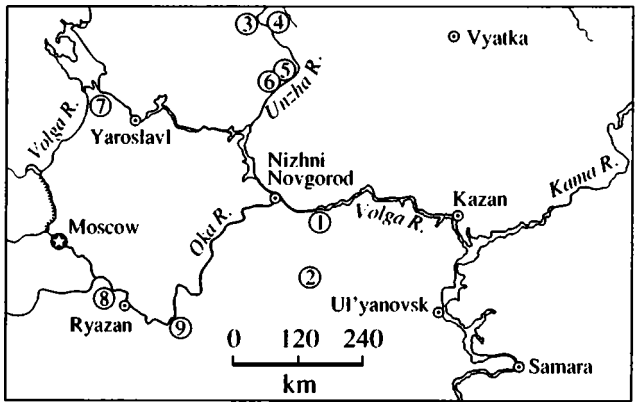

Fig. 1. Location of the studied upper Bathonian–lower Callovian sections in Central Russia: 1, Prosek-Isady; 2, Uzhovka; 3, Akatovo; 4, Pezhenga; 5, Manturovo-Znamenka; 6, Ivkino; 7, Cheremukha; 8, Alpat'evo; 9, Nikitino.

Unzha River between the Ivkino and Samylovo villages); (7) the Cheremukha section (the Yaroslavl area, an outcrop at the right bank of the Cheremukha River near the Dmitrievka Village); (8) the Alpat'evo section (the Moscow area, a series of outcrops at the right bank of the Oka River near the Alpat'evo Settlement); and (9) the Nikitino section (the Ryazan area, an outcrop at the right bank of the Oka River near the Nikitino Village).

The Prosek-Isady, Uzhovka, Pezhenga and Alpat'evo sections, which are most rich in fossils and best studied, are described below.

The Prosek-Isady Section (Fig. 2)

In the quarry located in northwestern outskirts of the Prosek Village (except for Bed 1) and in a series of outcrops at the right bank of the Volga River between the Prosek and Isady villages, the following beds rest on the uneven surface of sandstones and clays of the Tatarian Stage of the Permian System:

(1) Yellowish gray and gray fine-grained silty micaceous sandstones, which are highly clayey at the base; the sandstones are intercalated with discontinuous interbeds and lenticular bodies of gray clayey sand. Locally they include small clayey pebbles, rare pyrite concretions, and small wood fragments. Approximately 2.5–3.5 m below the bed top, there occur rare ball-like concretions of carbonate sandstone up to 0.7 m in diameter. The ammonite assemblage **a1** is discovered from the interval of 1.5–4.5 m below the top and from concretions, and the assemblage **a2** characterizes the interval of 0–1 m (Fig. 2). The bed thickness is 8–10 m.

(2) Dark gray micaceous massive clay; the lower sandy part of the bed includes lenticular basal interbeds of highly sandy clay, clayey sand, and silt up to 1 m thick. The bed is separated from the preceding one by finely alternating and plicated laminae of clay and sand about 5 cm thick. The bed contains scattered pyrite concretions, crystalline gypsum aggregates, and rare fragments of pyritized wood. Flattened septaria of compact gray marl up to 1 m in diameter occur approximately 5–8 m below the top, and rare small marl concretions are found also at the top of the bed. The ammonite assemblage **a3** is confined to the interval of 0–1.4 m above the base; the assemblage **a4** is predominantly concentrated in the middle and upper thirds of the bed, the enclosed concretions included; and assemblages **a5** and **a6** are characteristic of the uppermost part of the bed and of the enclosed concretions (Fig. 2). The bed thickness is 12–15 m.

(3) Greenish gray medium-grained sand locally with coalified plant remains; the bed has uneven contact with the preceding one. The bed thickness is 0.4 m.

(4) Yellow and yellowish brown clay silts and siltstones with interbeds and separate concretions of brownish gray oolitic marl; the ammonite assemblages **a7** and **a8** are confined to the lower half of the bed (Fig. 2). Above there are rare ammonites of the assemblage **a9** (Fig. 2). The assemblage **a10** is found near the bed top (Fig. 2). The bed thickness is 0.2–0.7 m.

These beds are overlain by gray carbonate clays of the Oxfordian(?)–Kimmeridgian age.

The Uzovka Section (Fig. 3)

The quarry in northwestern outskirts of the Uzhovka Settlement exhibits the following beds:

(1) Light gray and white micaceous cross-bedded sand with thin (up to 1–4 cm) lenticular interbeds of gray sandy clay; apparent thickness of the bed is up to 3 m.

(2) Dark gray micaceous, massive clay slightly sandy in the basal and middle parts of the bed; pyrite concretions, fragments of pyritized wood, and rare concretions of gray marl are scattered in the bed that yielded successive ammonite assemblages **b1**, **b2**, **b3**, and **b4** (Fig. 3). The bed thickness is 8–10 m.

(3) Dark gray and brownish gray silt, which becomes sandy downward being locally oolitic; the bed has uneven contact with the previous one. The basal thin interbed of shell detritus contains the ammonite assemblage **b5a** (Fig. 2). In the top portion, concretions of gray oolitic marl bear the ammonite assemblage **b5b** (Fig. 3). The bed thickness is 0.2–0.4 m.

Above there are condensed silts and marls enclosing the diverse fossils the middle Callovian *Jason* and *Coronatum* zones.

The Pezhenga Section (Fig. 4)

The outcrop at the left bank of the Unzha River downstream from the Pezhenga River mouth exhibits the following bed sequence:

(1) Light gray and white, locally ferruginous and slightly micaceous loose sand that is intercalated with thin (up to 1 cm) lenticular clay interbeds; the bed contains rare fragments of coalified wood. Apparent thickness is 1.3 m.

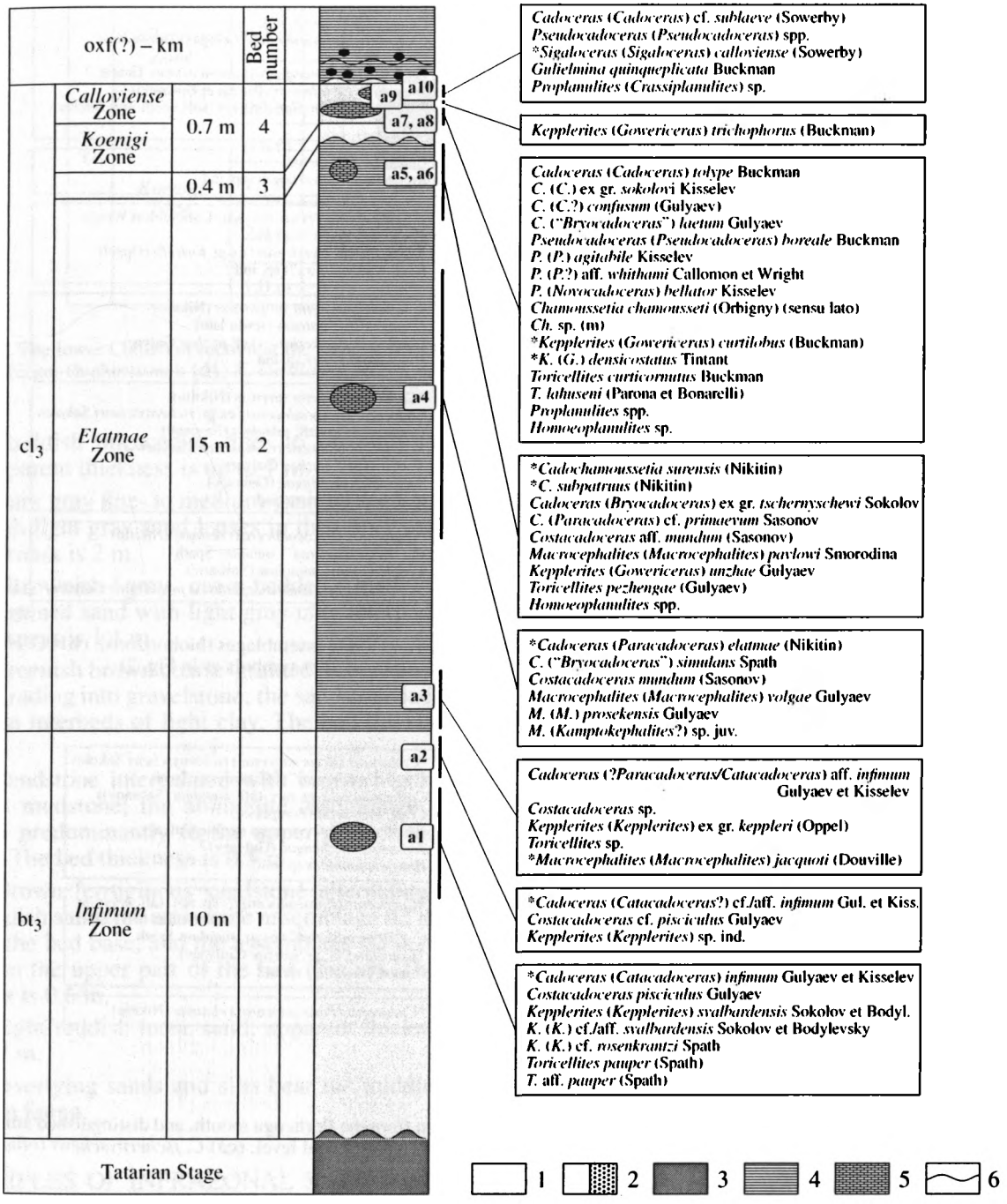

Fig. 2. The composite Jurassic section at the Prosek-Isady site and levels of distinguished ammonite assemblages (biohorizons): (**a1**) *C. infimum*; (**a2**) *C.* cf./aff. *infimum*; (**a3**) *M. jacquoti*; (**a4**) *C. elatmae*; (**a5**) *C. surensis*; (**a6**) *C. subpatruus*; (**a7**) *K. densicostatus*; (**a8**) *K. curtilobus*; (**a9**) *K. trichophorus*; (**a10**) *S. calloviense* (index species of the biohorizons are indicated by asterisks). Lithology: (1) silt and siltstone; (2) sand; (3) sandstone; (4) clay; (5) concretions; (6) stratigraphic hiatus.

(2) Dark gray, locally almost black, slightly micaceous, compact and occasionally ferruginous sand with fragments of carbonaceous wood; the bed thickness is 0.3 m.

(3) Light gray loose sand; the bed thickness is 0.15 m.

(4) Dark gray micaceous and clayey condensed sand enclosing coalified wood and a horizon of flattened concretions of black phosphoritized sandstone; concretions bear rare ammonites representing the assemblage **c1** (Fig. 4). The bed thickness is 0.12 m.

(5) Light gray micaceous sand grading into light brown compact sandstone with coalified wood fragments; the bed thickness is 0.6 m.

(6) Gray micaceous and clayey, locally ferruginous compact sand with clay interbeds; the bed thickness is 0.5 m.

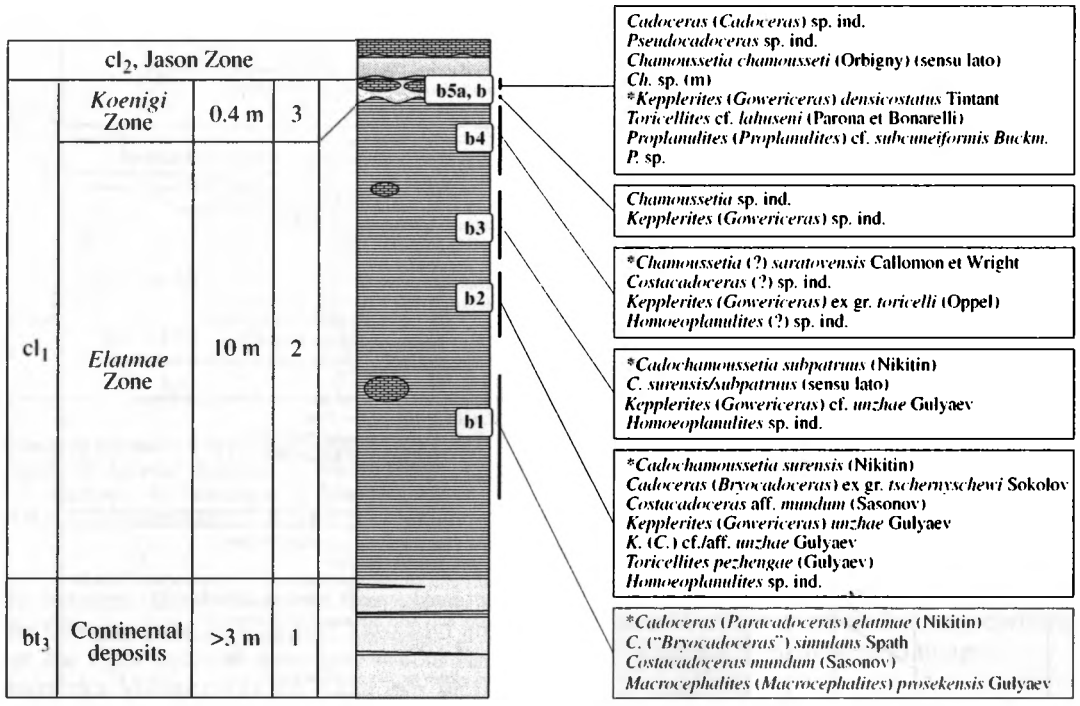

Fig. 3. The composite Jurassic section at the Uzhovka site and distinguished ammonite assemblages (biohorizons): (**b1**) *C. elatmae*; (**b2**) *C. surensis*; (**b3**) *C. subpatruus*; (**b4**) *Ch. saratovensis*; (**b5**) *K. densicostatus* (other symbols as in Fig. 2).

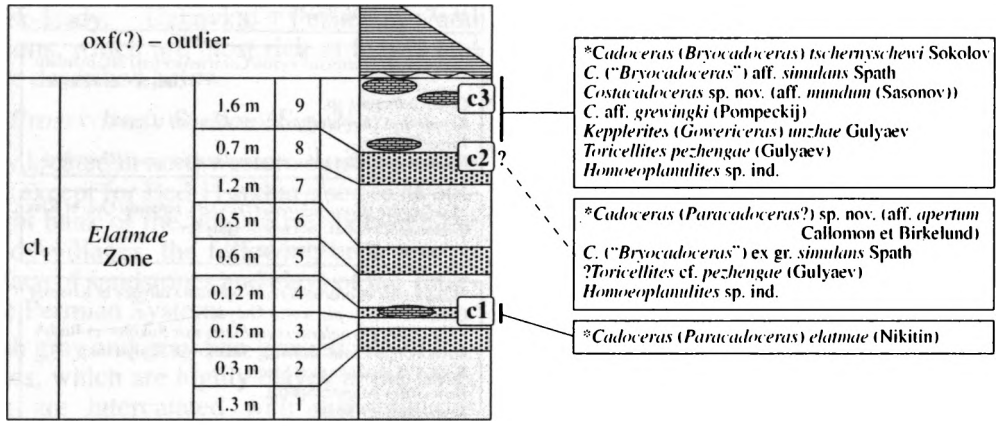

Fig. 4. The Jurassic section at the left bank of the Unzha River, downstream from the Pezhenga mouth, and distinguished ammonite assemblages (biohorizons): (**c1**) *C. elatmae*; (**c2**) *C.* sp. nov. (aff. *apertum*), hypothetical level; (**c3**) *C. tschernyschewi* (other symbols as in Fig. 2).

(7) Light gray and loose micaceous, locally ferruginous sand; the bed thickness is 1.2 m.

(8) Sand analogous to that of Bed 6; the bed thickness is 0. 7m.

(9) Sand analogous to that of Bed 7; in the intervals of 10–20 cm above the bed base and 10–50 cm below the top, there are lenticular interbeds of gray sandy clay 0.5–10 cm thick. The interbeds contain flat septaria of black phosphoritized mudstone. The bed yielded the ammonite assemblage **c3** (Fig. 4). The ammonite assemblage **c2** may characterize the basal part of the bed (Fig. 4). However, it is difficult to define the precise location of the last assemblage that is recovered from a concretion found in the talus. The bed thickness is 1.6 m.

Above, there is bed of black micaceous clay varying in thickness. It contains crushed shells of Cardioceratidae supposed to be Oxfordian in age.

The Alpat'evo Section (Fig. 5)

The series of outcrops at the right bank of the Oka River exhibits the following beds:

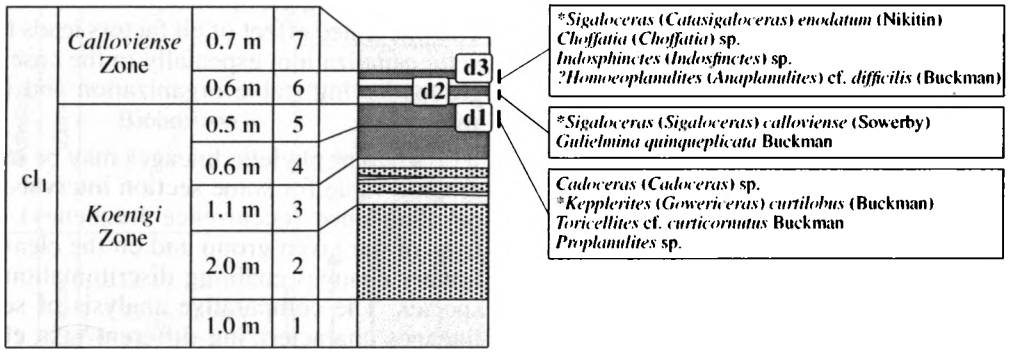

Fig. 5. The lower Callovian section at the right bank of the Oka River near the Alpat'evo Settlement and distinguished ammonite assemblages (biohorizons): (**d1**) *K. curtilobus*; (**d2**) *S. calloviense*; (**d3**) *S. enodatum* (other symbols as in Fig. 2).

(1) Reddish micaceous, fine- to medium-grained sand; apparent thickness is up to 1 m.

(2) Dark gray fine- to medium-grained sand intercalated with light gray sand lenses in the upper part; the bed thickness is 2 m.

(3) Brownish gray cross-bedded, medium- to coarse-grained sand with light gray clay interbeds; the bed thickness is 1.1 m.

(4) Greenish brown coarse-grained, loose sandstone locally grading into gravelstone; the sandstone includes basal thin interbeds of light clay. The bed thickness is 0.6 m.

(5) Sandstone intercalated with brown highly ferruginous mudstone; the ammonite assemblage **d1** is confined predominantly to the upper part of the bed (Fig. 5). The bed thickness is 0.5 m.

(6) Brown ferruginous sandstone alternating with light reddish sand; the ammonite assemblage **d2** is confined to the bed base, and the assemblage **d3** is recovered from the upper part of the bed (Fig. 5). The bed thickness is 0.6 m.

(7) Light reddish loose sand; apparent thickness is up to 0.7 m.

The overlying sands and silts bear the middle–late Callovian fauna.

PRINCIPLES OF INFRAZONAL SUBDIVISION

The Jurassic ammonite stratigraphy in Western Europe is predominantly elaborated at the precision level of subzones (Callomon, 1984, 1985, 1993; Callomon *et al.*, 1988, 1989, 1992; Page, 1995; and many others). Regretfully, this approach is of a limited acceptance in Russia. Subdivision up to subzones greatly increases resolution of local and regional scales, makes their correlation more precise, and reveals many local biotic and geological events, which cannot be distinguished when units of a higher rank are in use.

Two detailed biozonations are used in practice. French stratigraphers usually operate with units called "zonules", whereas English and German researchers use the term "biohorizon" that is more convenient in my opinion and closer related to biological events.

Zonule is the smallest chronostratigraphic unit defined, like units of higher ranks, by its lower boundary in the stratotype section. Page (1995) estimated that an average time range of zonule (biohorizon plus a potential hiatus) is about 200000 or, occasionally, only 80000 years.

Biohorizon (or *faunal horizon*) may correspond to a bed, or to a part of the bed and even to a bed sequence, when they yield a peculiar fossil assemblage (fauna or flora) that cannot be differentiated further in stratigraphy (Callomon, 1985). Therefore, both the lower and upper boundaries of biohorizon are detectable in a concrete section (Page, 1995). For the chronoequivalent of biohorizon, Callomon (1985) suggested the term "hemera" introduced by Buckman (1893, 1902).

Biohorizon is recognizable in a section, or in a series of sections of some region, if its index species (subspecies) is identified; taxonomic composition of associated fossils is of auxiliary importance only. It is expedient to use species (subspecies) of a single phyletic line as index taxa of successive biohorizons. As suggested by Callomon (1985), the possible highest resolution can be achieved by using transient species usually denoted by Greek letters. Successive biohorizons may have boundaries, which do not coincide. In correlation charts, potential hiatuses are indicated by intervals separating the neighboring units. Being established, the succession of biohorizons should be integrated with the existing zonal scale. At the present state of knowledge, boundaries and summary ranges of biohorizons may not coincide with those of higher rank units (Page, 1995), although such a coincidence should be aimed at.

As a rule, biohorizons are most convenient for correlation within biogeographic provinces, but some biohorizons or their successions can be stratigraphically significant for paleobiogeographic realms and even used as interregional markers.

The studied vertical successions and concurrent ranges of ammonite species enabled recognition of a

series of faunal assemblages stratigraphically outlining biohorizons of the upper Bathonian–lower Callovian sections (Figs. 2–5, Table 1). Their recognition and correlation were facilitated by the distinct species successions (phyletic lineages) established in subfamilies Cadoceratinae Hyatt, Gowericeratinae Buckman, and Macrocephalitinae Salfeld (Fig. 6). Every phyletic lineage shows persistent changes in species morphology (phyletic trend), which offer a basis to find the proper position of individual species in the general succession. However, the precise dating of faunal assemblages should be based on representative material elucidating variability of the constituent species, because the end members of isochronous (intraspecific) variation lines may have a set of either archaic or progressive features making them similar to ancestors or descendants, respectively, for which the given combination of distinctive features is a norm.

Examples can be found every time, when we have the representative collection of fossils. For instance, among abundant shells of *Kepplerites (Kepplerites) svalbardensis* Sok. et Bodyl. of the assemblage **a1** from the Prosek-Isady section (Fig. 2), there are some specimens similar in their coarse ribbing to *K. (K.)* ex gr. *keppleri* (Opp.) of the assemblage **a3**. Another example is the subfamily Cadoceratinae. In the Uzhovka section (Fig. 3), the dominant representatives characterizing one of the successive species *Cadochamoussetia surensis* (Nik.), *C. subpatruus* (Nik.), and *Chamoussetia (?) saratovensis* Call. et Wright (assemblages **b2**, **b3**, and **b4**, respectively) associate at every particular level with the intermediate forms resembling in some characters the neighboring species of the given phyletic lineage. Assuming coexistence of these species, we come into collision with the principle of competitive exclusion of ecologically similar forms (the Gauze rule). In addition, it is evident that the coexistence of evolutionary allied species presupposes the preceding divergence and, at least, the initial isolation of species. Mechanism of such isolation is difficult to explain. Therefore, the model of phyletic (nondivergent) speciation seems to be more preferable.

The coexistence of archaic and progressive morphotypes of a single species can be explained in terms of the stabilizing selection theory (Shmal'gauzen, 1968; Shishkin, 1988; and others), according to which the speciation is related to the appearance of a new norm (a certain stable morphological-functional and genetic state). In population, where dominant representatives correspond to this norm, some forms may still have features corresponding in a certain sense to the previous norm, and, simultaneously, the combination of future standard features is under development.

The steady unidirectional evolution of individual phyletic lineages can be explained by limits of potential transformations controlled by the evolutionary ability of a given organization type, on the one hand, and by the environmental impact of abiotic and biotic factors on the evolving group of organisms, on the other hand. The integrated effect of all factors leads to the phylogenetic canalization, especially in the case of specialized groups having stable organization and low ecological valence.

Particular phyletic lineages may be of a great stratigraphic value for some section intervals. This depends on abundance (occurrence frequency) of representatives of the given group and on the clearness of evolutionary changes enabling discrimination of successive species. The comparative analysis of several phyletic lineages characterizing different taxa effectively controls the recognition and correlation of biohorizons.

Critical for recognition of infrazonal subdivision in the *Infimum* Zone and in the lower part of the *Elatmae* Zone is the phyletic lineage of Cadoceratinae: *Cadoceras (Catacadoceras) infimum* Gul. et Kiss – *C. (C.)* cf./aff. *infimum–C.(?Paracadoceras/Catacadoceras)* aff. *infimum* (Fig. 6, nos.1–3). This phyletic lineage demonstrates the transition from representatives of the subgenus *Catacadoceras* Bodylevsky, which retain coarse ribbing on body chamber throughout the mature stage, to representatives of the subgenus *Paracadoceras* Crickmay, which have fine ribbing smoothening during the ontogenesis. The evolutionary transition from the fine-ribbed *Kepplerites (Kepplerites) svalbardensis* Sok. et Bodyl. to the relatively coarse-ribbed *K.(K.)* ex gr. *keppleri* (Opp.) (Fig. 6, nos. 21–22) is also of stratigraphic importance for the indicated interval.

Important for the lower and middle parts of the *Elatmae* Zone is also the phyletic lineage of scarce but characteristic species of Macrocephalitinae: *Macrocephalites (Macrocephalites) jacquoti* (Douv.)–*M.(M.) prosekensis* Gul.–*M.(M.) pavlowi* Smor. (Fig. 6, nos. 31–33). The succession shows the ventral side narrowing until its sharpening in the early whorls of *M.(M.) pavlowi* and reduction of sculpture on lateral sides.

By subdivision of the middle and upper parts of the *Elatmae* Zone and of the basal part of the *Koenigi* Zone, the key role belongs to the phyletic lineage of Cadoceratinae: *Cadoceras (Bryocadoceras) tschernyschewi* Sok.–*Cadochamoussetia surensis* (Nik.)–*C. subpatruus* (Nik.)–*Chamoussetia (?) saratovensis* Call. et Wright–*Ch. chamousseti* (Orb.) (*s.l.*) (Fig. 6, 6–10). This phyletic lineage is characterized by the rapid transformation of shell morphology from cadicone (*C. (B.) tschernyschewi*) to oxycone (*Chamoussetia*).

The phyletic lineage of Gowericeratinae takes origin in the *Elatmae* Zone and is characteristic of the *Koenigi* and *Calloviense* zones in subboreal regions of Europe and eastern Greenland. This lineage is as follows: group of *Kepplerites (Gowericeras) unzhae* Gul.–group of *K.(G.) toriceli* (Opp.)–species of the group of *K.(G.) gowerianus* (Sow.) and *K.(G.) metorchus* (Buckm.)–*K.(G.) densicostatus* Tint.–*K.(G.) curtilobus* (Buckm.)–*K.(G.) trichophorus* (Buckm.) [?=*K.(G.) galilaeii* (Opp.) *sensu* Page, 1989]–species

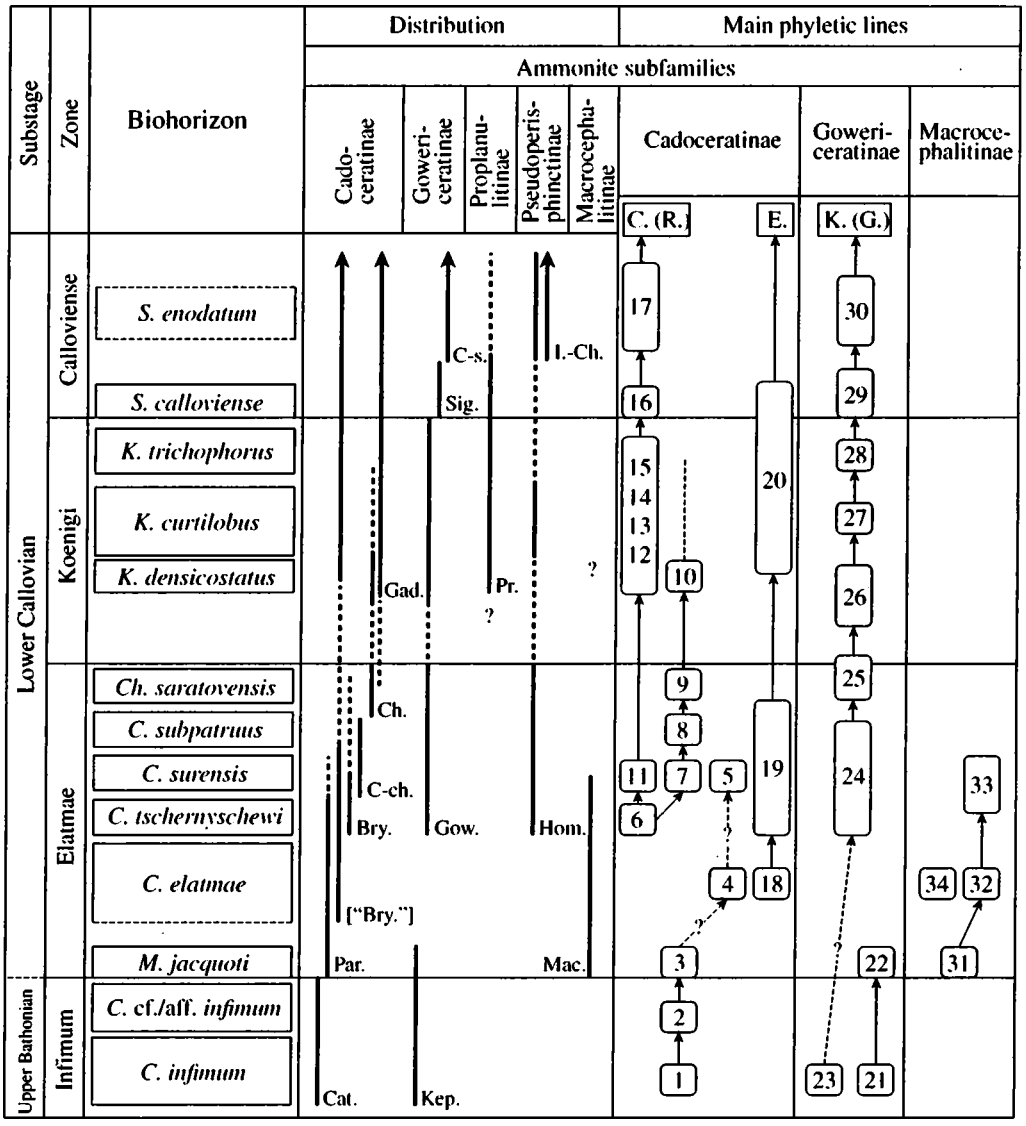

Fig. 6. Stratigraphic ranges of genera and subgenera of ammonite macroconchs and main phyletic lineages of Cadoceratinae, Gowericeratinae and Macrocephalitinae, the upper Bathonian–lower Callovian of Central Russia (ranges of index species and biohorizons are shaded).

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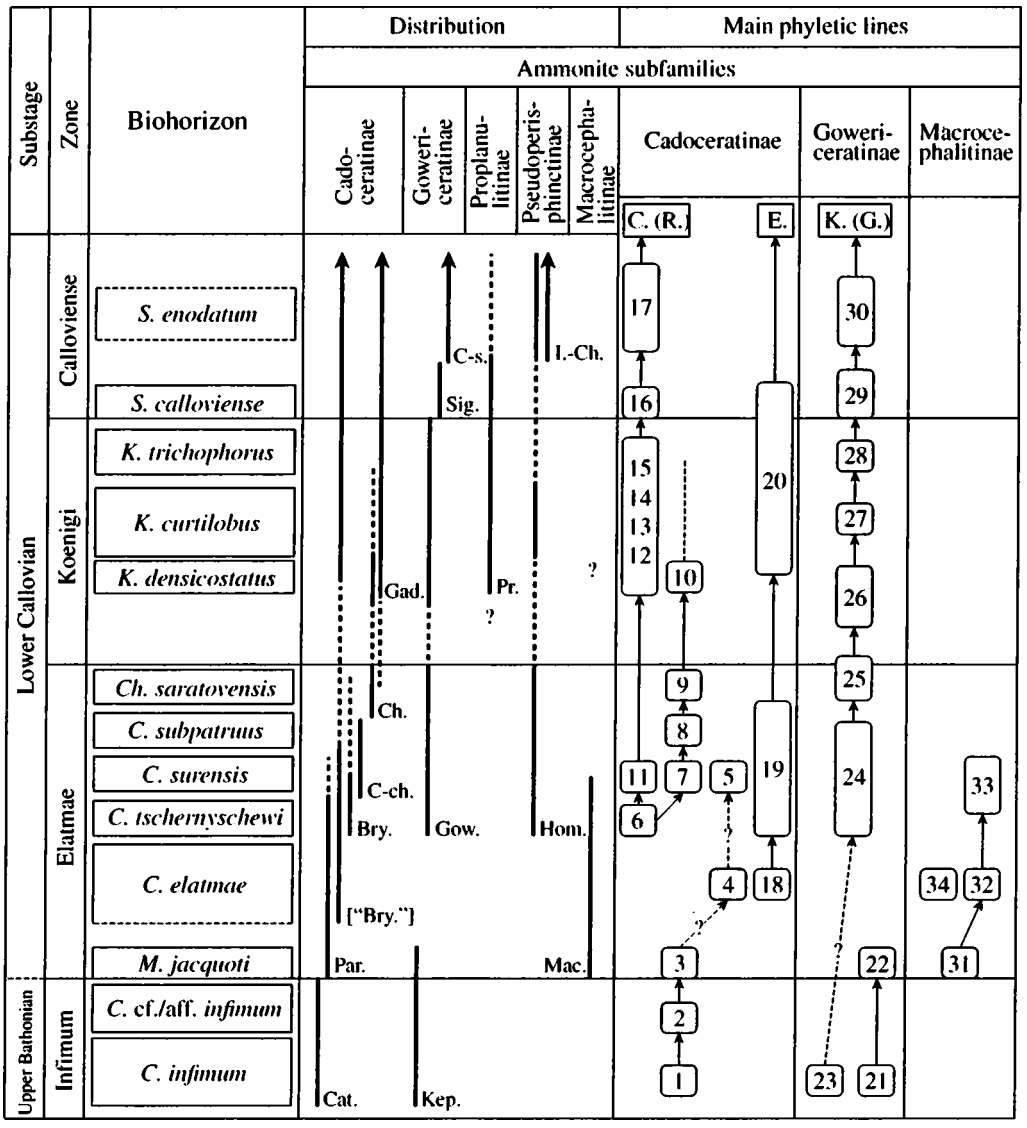

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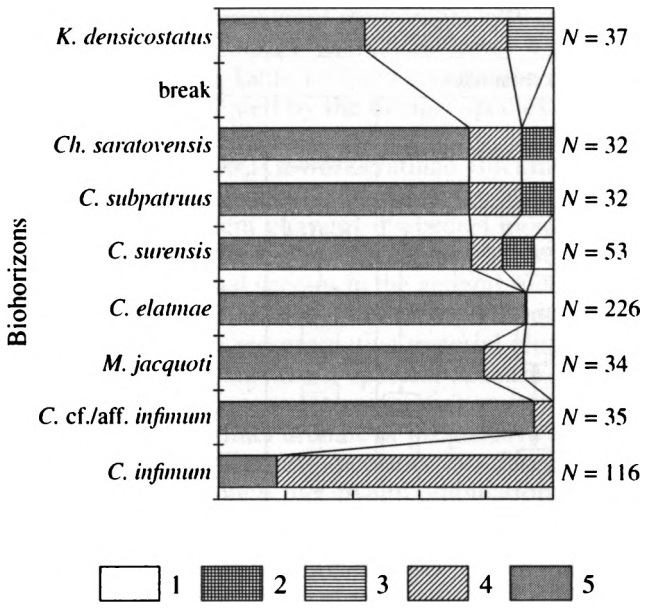


Fig. 7. Dynamics of relative abundance of ammonite subfamilies in the *Infimum* and *Elatmae* zones and at the base of the *Koenigi* Zone in the Nizhnii Novgorod area (the Prosek-Isady and Uzhovka sections): (1) Macrocephalitinae; (2) Pseudoperisphinctinae; (3) Proplanulitinae; (4) Gowericeratinae; (5) Cadoceratinae.

of the group of *Sigaloceras (Sigaloceras) calloviense* (Sow.) and *S.(S.) micans* Buckm.–group of *S. (Catasigaloceras) enodatum* (Nik.) (Fig. 6, nos. 24–30). In this case, we observe the gradual transition from forms, which have wide coarse-ribbed echinate whorls, the relatively high ribbing density on the terminal body chamber, and wide umbilicus (*K.(G.) unzhae*), to other forms having the high fine-ribbed whorls, widely spaced broad or completely smoothen primary ribs on the terminal body chamber, and narrow umbilicus (*Sigaloceras*).

In addition to Gowericeratinae, Cadoceratinae and Perisphinctidae are the main groups characterizing the *Koenigi* and *Calloviense* zones. However, phylogenetic links within these groups are insufficiently known (especially in the latter), and their significance for detailed stratigraphy is uncertain. For instance, the subfamily Cadoceratinae reveals transition from forms similar to *Cadoceras (Cadoceras) tolype* Buckm. to the forms similar to *C.(C.) sublaeve* (Sow.) and *C.(C.?) tschefkini* (Orb.), and finally to the subgenus *Rondiceras* Troitskaya (Fig. 6, nos. 12–17). By this transition, ribbing becomes reduced and narrows umbilicus of the early whorls grows wider afterward. However, in addition to this general trend, there could be some deviating or even parallel lines responsible for origin of *C.(C.?) confusum* (Gul.), *C. ("Bryocadoceras") proniense* Sas., and some other species.

Species of the subfamily Cadoceratinae distinctly dominate components in most assemblages of the *Infimum* and *Elatmae* zones (Fig. 7). Accordingly, they can be used as index species of most biohorizons spanning this stratigraphic interval. Representatives of the subfamily Gowericeratinae serve as index species of biohorizons established in the *Koenigi* and *Calloviense* zones, where these forms are abundant.

THE UPPER BATHONIAN–LOWER CALLOVIAN INFRAZONAL SCALE

The upper Bathonian–lower Callovian zones and biohorizons of Central Russia are characterized below. Also presented in the article are infrazonal correlation schemes of the described sections (Table 1), the upper Bathonian–lower Callovian stratigraphic scales for Central Russia, Northwest Europe, eastern Greenland, and Northern Siberia (Table 2), as well as stratigraphic ranges of ammonite taxa (Fig. 6) and dynamics of relative abundance of ammonite subfamilies in the *C. infimum–K. densicostatus* biohorizons (Fig. 7).

Upper Bathonian

Infimum Zone

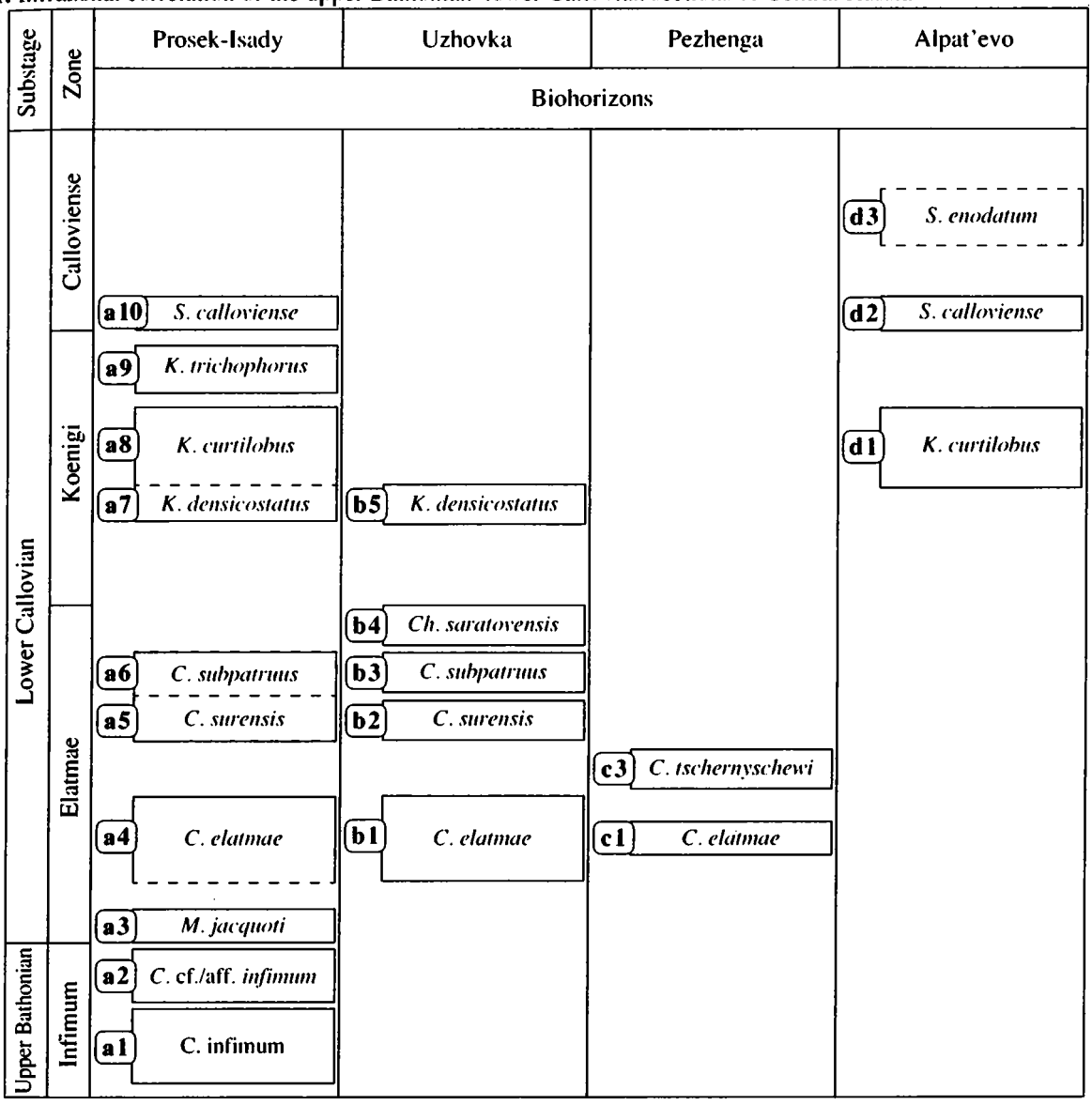
Index species: *Cadoceras (Catacadoceras) infimum* Gulyaev et Kisselev, 1999. The holotype no. 2/627 from the Prosek-Isady section, Nizhni Novgorod area, (Gulyaev and Kiselev, 1999, Plate I, fig. 1) is stored at the Chair of Zoology of the Yaroslavl State University.

Nomenclature. The local *Infimum* Zone is established on the basis of peculiar fauna discovered below the *Elatmae* Zone of the Middle Volga region (Gulyaev and Kiselev, 1999).

Paleontological characteristics. The *Infimum* Zone corresponds to the earliest formation stage of the East European sea basin prior to its connection with the Tethyan and West European seas. The ammonite fauna of exclusively boreal (arctic) origin includes archaic representatives of subfamilies Cadoceratinae Hyatt (*Cadoceras (Catacadoceras)* Bodylevsky [M] and *Costacadoceras* Rawson [m]) and Gowericeratinae Buckman (*Kepplerites (Kepplerites) Neumayr* [M] and *Toricellites* Buckman [m]). Similar assemblages were previously known only from the upper Bathonian deposits of the Arctic regions, namely from eastern Greenland (Spath, 1932; Callomon, 1993; and others) and Spitsbergen (Ershov, 1983; Kopik and Wierzbowski, 1988; and others). The distinct predominance of Gowericeratinae in the lower part of the zone and of Cadoceratinae in the upper one serves as a basis for distinguishing the respective biohorizons. Changes in abundance are interrelated with morphological transformations. In the upper part of the zone, representatives of *C. (Catacadoceras)* group demonstrate less coarse ribbing and *K. (Kepplerites)* forms show wider spaced primary ribs on the mature body chamber.

Stratigraphic position. The *Infimum* Zone cannot be directly correlated with the standard West European

Table 1. Infrazonal correlation of the upper Bathonian–lower Callovian sections of Central Russia



scale because of a high geographic differentiation of ammonite faunas. According to its position below the *Elatmae* Zone, the *Infimum* Zone most likely corresponds to the *Discus* Zone. Owing to ambiguous correlation of the lower boundary of the *Elatmae* Zone (see below), the *Infimum* Zone range may vary in scope within the interval of the *Discus* Zone coupled with the upper part of the *Orbis* Zone. The lower part of the *Infimum* Zone (*C. infimum* Biohorizon) can be indirectly correlated with the upper *Hannoveranus* Subzone of the *Orbis* Zone, as it follows from the *Kepplerites* form found at this level in Bavaria. The form found is similar to the index species of the lower *K. peramplus* Biohorizon of the *Calyx* Zone of eastern Greenland (Dietl and Callomon, 1988). This biohorizon is directly correlative with the *C. infimum* Biohorizon on the basis of ammonites.

The boreal origin of ammonite faunas allows the *Infimum* Zone to be correlated with the Arctic zonal and infrazonal scales. As shown below, similarity and even identity of *Kepplerites* species validates correlation between biohorizons of the *Infimum* and *Calyx* zones of eastern Greenland.

The index species of the *Infimum* Zone is similar to *C.(C.) barnstoni* (Meek) representing the index species of the upper Bathonian zone that is recognized in the Northern Yukon region, Arctic Canada (Poulton, 1987), and Northern Siberia (Meledina, 1991, 1994). In eastern Greenland, forms similar to *C. (C.) barnstoni* are recorded predominantly in upper beds of the *Variabile* Zone, but some later representatives of *C. (Cataca-doceras)* group were found at the base of the *Calyx* Zone (Callomon, 1993). Most likely, the *Infimum* Zone,

Table 2. Correlation of the upper Bathonian–lower Callovian zonal and infrazonal scales for Central Russia, northwestern Europe, eastern Greenland, and northern Siberia (author's interpretation)

Note. Abbreviations designate the following taxa: (B.) *Bullatimorphites*, (C.) *Cadoceras*, (Calov.) *Calloviense*, (Ch.) *Chamoussetia*, (Cl.) *Clidoniceras*, (Gal.) *Galilaeii*, (H.) *Homoeoplanulites*, (Hann.) *Hannoveranus*, (Holl.) *Hollandi*, K. *Kepplerites*, (M.) *Macrocephalites*, (Nordensk.) *Nordenskjoeldi*, (O.) *Oxycerites*, (S.) *Sigaloceras*, (Terebr.) *Terebratus*, (Var.) *Variabile*.

as well as the *Calyx* Zone, should be correlated with the upper part of the *Barnstoni* Zone of Siberia.

Distribution. At present, the *Infimum* Zone is reliably established in the Prosek-Isady section only. However, it seems to be present not only in middle courses of the Volga River, but also in northern and eastern areas of European Russia (in accordance with the supposed configuration of the paleobasin).

C. infimum Biohorizon

Index species: *Cadoceras (Catacadoceras) infimum* Gulyaev et Kisselev.

Nomenclature. The *C. infimum* Biohorizon is established in the upper part of sands underlying clays of the *Elatmae* Zone of the Prosek-Isady section (Gulyaev and Kiselev, 1999). My subsequent study in 1998 revealed two successive ammonite assemblages confined to this level. The lower assemblage (Fig. 2, **a1**) shows paleontological characteristics initially suggested for the *C. infimum* Biohorizon.

Paleontological characteristics. Representatives of subfamily Gowericeratinae, the dominant and highly variable *Kepplerites (Kepplerites) svalbardensis* Sok. et Bodyl. included, constitute approximately 80% of the ammonite assemblage (Plate I, Fig. 4). Few found specimens of *K. (K.)* cf. *rosenkrantzi* Spath have wide echinate early whorls decorated with coarse ribs. Microconchs of *Toricellites pauper* (Spath) and *T.* aff. *pauper*, the latter with coarser ribs, represent up to 10–15% among all forms of Gowericeratinae. About 20% of ammonites belong to subfamily Cadoceratinae represented by species *C.(C.) infimum* Gul. et Kiss. (Plate I, fig. 5) and *Costacadoceras pisciculus* Gul., which have coarse ribbing at the intermediate to late stages of growth and slightly involute whorls of shell up to 5 or 6 cm in diameter.

Stratigraphic position. The *C. infimum* Biohorizon corresponds to the lower part of the *Infimum* Zone. The ammonite assemblage of the biohorizon is similar to that of the upper Bathonian deposits in eastern Greenland, as they both include common *Kepplerites* forms (Callomon, 1993). *K. (K.) svalbardensis* of the *C. infimum* Biohorizon was reported from the lower *K. peramplus* Biohorizon of the *Calyx* Zone of eastern Greenland, and *K. (K.). rosenkrantzi* is characteristic of the synonymous upper biohorizon of the preceding *Variabile* Zone. Typical forms of the latter belong to the subgenus *Cadoceras (Catacadoceras)*, although younger representatives of this subgenus are also recorded at the base of the *Calyx* Zone. Thus, at the first sight, ammonite fauna of the *C. infimum* Biohorizon corresponds to that characterizing two biohorizons of eastern Greenland, where each bears its peculiar set of species. Such a conclusion is misleading, because all ammonites of the *C. infimum* Biohorizon were found associated in the same concretions. Most likely, the *C. infimum* Biohorizon should be correlated with the lower half of the *Calyx* Zone (the *K. peramplus* Biohorizon), where the assemblage is dominated by *K. (K.) svalbardensis*. Callomon (Dietl and Callomon, 1988; Callomon, 1993) correlates the *Calyx* Zone with the standard *Orbis* Zone of Western Europe, because its upper *Hannoveranus* Subzone in Bavaria contains *Kepplerites (Kepplerites)* cf./aff. *peramplus* Spath similar to that from eastern Greenland. It is difficult to evaluate how reliable is this version, but from the last standpoint, the *C. infimum* Biohorizon should also be correlated with the upper part of the *Orbis* Zone.

Distribution: the same as that of the zone as a whole.

C. cf./aff. *infimum Biohorizon*

Index species: the form tentatively identified as *Cadoceras (Catacadoceras?)* cf./aff. *infimum* Gul. et Kiss. Because of the poor preservation state, it is still unclear whether this form represents an independent species or the transient *C.(C.) infimum* variety.

Nomenclature. The *C.* cf./aff. *infimum* Biohorizon is established in the uppermost sands underlying clays of the *Elatmae* Zone in the Prosek-Isady section (Fig. 2, assemblage **a2**). The unit is contiguous to the *C. infimum* Biohorizon.

Paleontological characteristics. Poorly preserved ammonites are identified in terms of open nomenclature. Species of subfamily Cadoceratinae represent more than 90% of the assemblage. *C. (C.?)* cf./aff. *infimum* greatly resembles the index species of the preceding biohorizon, but it has less coarse ribbing. *Costacadoceras* cf. *pisciculus* is almost indistinguishable from *C. pisciculus* typical of the underlying deposits. The subfamily Gowericeratinae is represented by rare specimens of *Kepplerites (Kepplerites)* sp. ind., which have ribbing slightly coarser than that of most specimens of *K. (K.) svalbardensis* from the preceding biohorizon.

Stratigraphic position. The *C.* cf./aff. *infimum* Biohorizon corresponds to the upper part of the *Infimum* Zone. According to its position relative to the previous biohorizon, the *C.* cf./aff. *infimum* Biohorizon should be correlated with the upper part of the *Calyx* Zone (the *K. vardekloeftensis* Biohorizon) of eastern Greenland. Depending on dating of adjacent levels, the *C.* cf./aff. *infimum* Biohorizon can be correlated to either the upper or lower part of the standard *Discus* Zone.

Distribution: the same as that of the zone as a whole.

Lower Callovian

Elatmae Zone

Index species: *Cadoceras (Paracadoceras) elatmae* (Nikitin, 1878). The neotype no. 34/1344 from the Ryazan' area near the town of Elat'ma (Nikitin, 1881, Plate 11 (4), fig. 20) is stored at the Chernyshev Geological Museum of St. Petersburg.

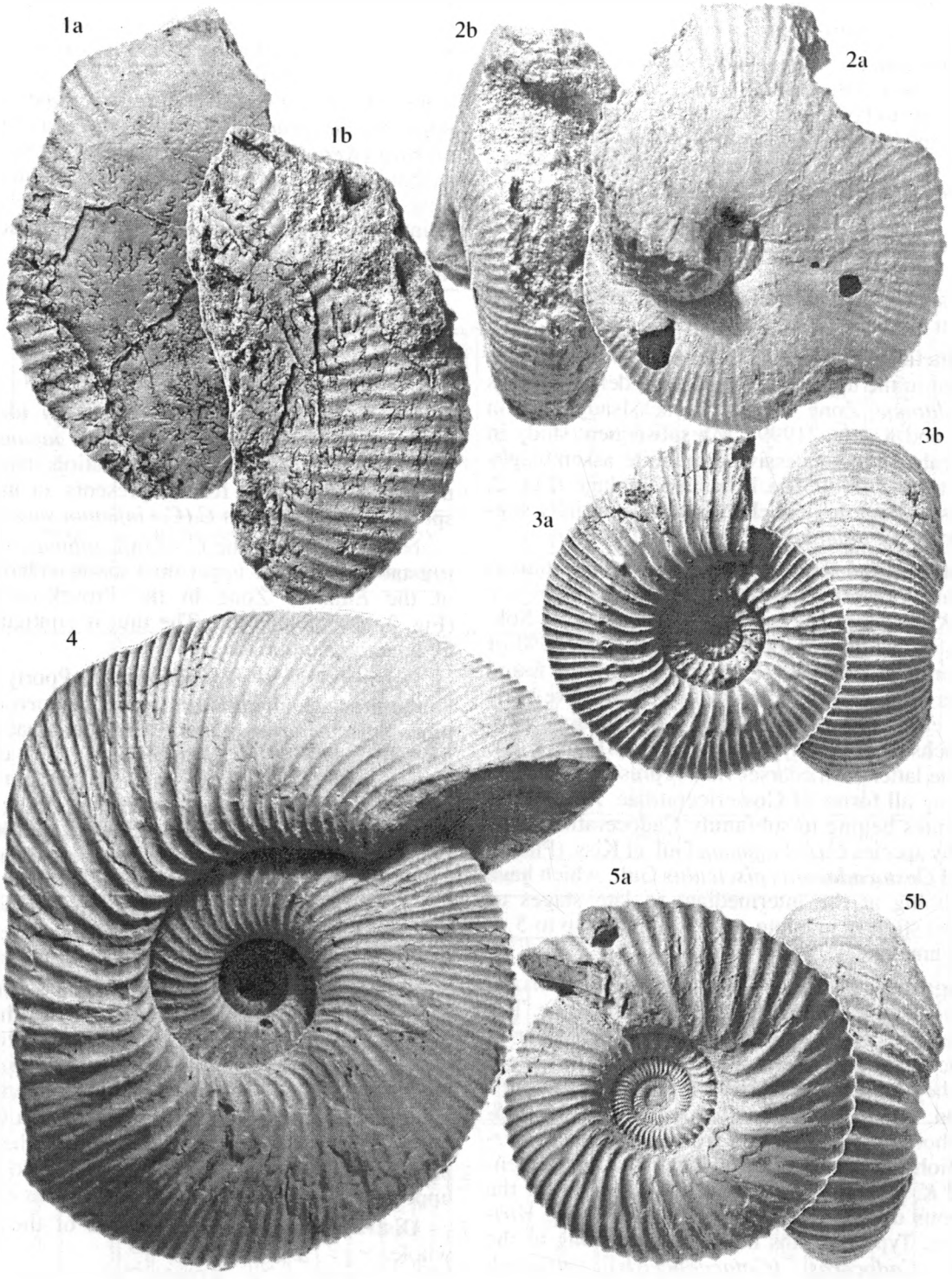


Plate I. Characteristic late Bathonian–early Callovian ammonite species of Central Russia (actual size)
(1) *Macrocephalites (Macrocephalites) jacquoti* (H. Douville), no. 2/1277: (1a) left view, (1b) right view; the Prosek-Isady section, *Elatmae* Zone, the *M. jacquoti* Biohorizon. (2) *M. (M.) jacquoti* (H. Douville), no. 8/1355: (2a) side view, (2b) ventral view; the Churkina section (the Pizhma River area, Komi Republic), *Elatmae* Zone, *M. jacquoti* Biohorizon. (3) *Kepplerites (Gowericeras) densicostatus* Tintant, no. 5/1175: (3a) side view, (3b) ventral view; the Uzhovka section, *Koenigi* Zone, *K. densicostatus* Biohorizon. (4) *K. (Kepplerites) svalbardensis* Sokolov et Bodylevsky, no. 2/676: side view; the Prosek-Isady section, *Infimum* Zone, *C. infimum* Biohorizon. (5) *Cadoceras (Catacadoceras) infimum* Gulyaev et Kisselev, the holotype no. 2/627: (5a) side view, (5b) ventral view; the Prosek-Isady section, *Infimum* Zone, *C. infimum* Biohorizon.

Nomenclature. "Stage of *Stephanoceras elatmae*" was distinguished for the first time by Nikitin (1881) in the Callovian deposits of the Elat'ma area in the scope of the entire lower Callovian.

The *Cadoceras elatmae* Zone suggested by Sazonov (1953) was officially authorized for the Russian platform at the All-Union Conference on the Unified Mesozoic Stratigraphic Scheme (*Resheniya...*, 1955). The zone was positioned above the *Arcticoceras ishmae* Zone and below the *Kepplerites calloviensis–K. gowerianus* Zone. It is characterized by the following zonal assemblage: *Macrocephalites macrocephalus* (Schloth.) [until the recent time, this was the traditional name for most *Macrocephalites* forms with discoid-conical shells], *Cadoceras elatmae* (Nik.), *C. modiolare* (Luid.) [=*C. simulans* Spath], *C. frearsi* (Orb.), *C. subpatruus* Nik., *Chamoussetia chamousseti* (Orb.) [probably, *Ch. (?) saratovensis* Call. et Wright, or morphologically similar *Macrocephalites pavlowi* Smor.], *Kepplerites gowerianus* (Sow.) [probably, *K. umzhae* Gul.], and others (Sazonov, 1953, 1957). Later (*Resheniya...*, 1962), the zone was named after two index species: *Cadoceras elatmae* and *Macrocephalites macrocephalus.*

When Meledina revealed that the *Elatmae* Zone yields only Cadoceratinae forms, the zone was denoted again after *C. elatmae*, and the underlying beds with *M. macrocephalus* were provisionally attributed to the lowermost Callovian (*Zony...*, 1982). Later Meledina (1986, 1987) concluded that there is no reliable evidence of *Macrocephalites* occurrence below the *Cadoceras* level in the Russian platform. Consequently, it is unnecessary to recognize the *Macrocephalites* level below the *Elatmae* Zone.

Analyzing vertical ranges of early Callovian ammonites in the Volga region near Saratov (the Malinovyi Ravine), Alekseev and Repin (1989), and afterward Repin and Rashvan (1996) suggested to change the nomenclature of the *Elatmae* Zone using the new index species *Costacadoceras mundum* (Sas.). They argued that *C. (P.) elatmae* is confined to the upper part of the zone, whereas only single *C. mundum* and *Macrocephalites (Macrocephalites)* cf. *triangularis* Spath. were found below. Accordingly, the *Mundum* Zone was subdivided into the *Macrocephalites* ex gr. *jacquoti* and *Cadoceras elatmae* subzones. However, it is a norm, when the index species range corresponds only to a part of the corresponding stratigraphic unit, and this is not a reason to change the unit name.

In this article, the *Elatmae* Zone is considered in approximately the same scope as initially suggested by Sazonov. Previously Kiselev and myself (Gulyaev and Kiselev, 1999; Gulyaev, 1999) pointed to the provisional character of the lower boundary of the *Elatmae* Zone. After the additional study of the Prosek-Isady section in 1998, this boundary was confidently establish at the first occurrence level of representatives of the genus *Macrocephalites* Zittel. This datum corresponds to the time, when the East European sea basin became connected with the Tethyan seas and entered the subboreal stage of development.

Paleontological characteristics. In the ammonite assemblages of the zone, dominant boreal forms are associated with some Tethyan taxa. The faunas are highly endemic.

The boreal subfamily Cadoceratinae Hyatt is dominant (75–90%) throughout the zone (Fig. 7). In the lower and middle parts of the zone, the subfamily is represented by species of the subgenera *Cadoceras (Paracadoceras)* Crickmay and, to a lesser extent, by those of *C. (Bryocadoceras)* Meledina. In the lower beds of the second half of the zone, the endemic genus *Cadochamoussetia* Mitta separates from the latter subgenus to give rise the genus *Chamoussetia* Douville characteristic of the upper beds. Species of these taxa are much more abundant than macroconchs of Cadoceratinae. Species of the group of *C. ("B.") simulans* Spath. occur sporadically but throughout the zone. Microconchs of the genus *Costacadoceras* Rawson also occur throughout the zone displaying the shell size diminishing, increasing ribbing density, and slightly growing involution of whorls.

Abundance of forms representing the low-boreal subfamily Gowericeratinae Buckman is not greater than 10–15% of the ammonite assemblages. At the base of the zone, the subfamily is represented by *Kepplerites (Kepplerites)* Neumayr and *Toricellites* Buckman, both retaining similarity with taxa of the previous *Infimum* Zone. Above (the *C. elatmae* Biohorizon), the Gowericeratinae forms disappear completely and occur again in the middle part of the zone, where the subfamily is represented by presumably endemic *K. (Gowericeras)* Buckman and *Toricellites* forms, which have wide echinate whorls in contrast to the earlier forms.

Scarce (not more than 10% of the assemblage) but characteristic species of the Tethyan subfamily Macrocephalitinae Salfeld were found in the lower and middle parts of the zone. Their occurrence suggests connections between the East European and Tethyan sea basins that was favorable for faunal exchange. Among the Macrocephalitinae forms, there are some peculiar and, most likely, endemic species.

Representatives of the Pan-Tethyan subfamily Pseudoperisphinctinae Shindewolf (the genus *Homoeoplanulites* Buckman) appear in the middle and upper parts of the zone representing up to 10% of the ammonite assemblages.

Stratigraphic position. In general, the *Elatmae* Zone is considered to be analogous to the basal Callovian *Herveyi* Zone of the standard scale. As shown below, some stratigraphic levels of both zones are correlative to each other owing to the occurrence of similar and identical representatives of genera *Cadoceras, Kepplerites*, and *Macrocephalites.* However, it is not improbable that the ambiguously dated lower boundary of the *Elatmae* Zone can be lowered down to the lower

part of the upper Bathonian *Discus* Zone of the standard scale (see below).

The occurrence of subgenera *Cadoceras (Paracadoceras)*, *C. (Bryocadoceras)*, and *Kepplerites (Kepplerites)* permits the *Elatmae* Zone to be correlated with the *Apertum* and *Nordenskjoeldi* zones of eastern Greenland (Callomon, 1993) and with the *Falsum* and *Anabarense* zones of northern Siberia (Meledina, 1994). The lower part of the *Elatmae* Zone may correspond to the *Bodylevskyi* Zone of the northern Yukon (Poulton, 1987).

Distribution. The *Elatmae* Zone can be recognized over the greater part of the European Russia.

M. jacquoti Biohorizon

Index species: *Macrocephalites (Macrocephalites) jacquoti* (H. Douville, 1878) [nom. nov. pro *Amm. Macrocephalus compressus* Quenstedt, 1849, p. 184, Plate 15, fig. 1].

Nomenclature. The *M. jacquoti* Biohorizon contiguous to the *C.* cf./aff. *infimum* Biohorizon is distinguished in basal clays of the *Elatmae* Zone of the Prosek-Isady section (Fig. 2, assemblage **a3**).

Paleontological characteristics. In general, the ammonite fauna inherits characteristics of the *Infimum* Zone assemblages. Up to 80%, it is constituted by representatives of the subfamily Cadoceratinae. The form identified as *Cadoceras (?Paracadoceras/Cataca-doceras)* aff. *infimum* differs from *C. (C.) infimum* and *C. (C.?)* cf./aff. *infimum* owing to more involute inner whorls and finer and denser ribbing. Ribbed shells of *C. (?P./C.)* aff. *infimum* are up to 60 mm in diameter. Their generic affiliation is uncertain, because the subsequent stages of growth are known. In contrast to *C. pisciculus*, microconchs of *Costacadoceras* sp. have smaller size and higher ribbing density. Representatives of the subfamily Gowericeratinae represent approximately 10% of the assemblage. Species *Kepplerites (Kepplerites)* ex gr. *keppleri* (Opp.) with coarser and wider spaced ribs are different from preceding forms of the genus. One microconch of *Toricellites* sp. that was found differs from older species *T. pauper*, since it has primary ribs wider spaced on the mature body chamber. The biohorizon in question marks the first occurrence level of representatives of the Tethyan subfamily Macrocephalitinae (*M. (M.) jacquoti* (Plate I, figs. 1, 2), which have discoid-conical shell with high rounded-triangular whorls and fine sculpture rapidly smoothening on lateral sides. The Macrocephalitinae forms represent about 10% of the ammonite assemblage.

Stratigraphic position. The *M. jacquoti* Biohorizon marks the lower boundary of the *Elatmae* Zone. The combination of *M. (M.) jacquoti* and *K. (K.) keppleri* characteristic of the basal *K. keppleri* Biohorizon of the North European *Herveyi* Zone (Callomon *et al.*, 1988, 1989, 1992; Page, 1989) indicates that these biohorizons are correlative. In Germany (Schwabia) however, *M. (M.) jacquoti* appears for the first time in the lower part (the *Hollandi* Subzone or *Cl. Hollandi* Biohorizon) of the *Discus* Zone (Callomon *et al.*, 1989). Forms similar to *K. (K.) keppleri* have a wide stratigraphic range (the *C. apertum* biohorizons) in eastern Greenland (Callomon, 1993). Owing to these facts, the *M. jacquoti* Biohorizon (and consequently, the base of the *Elatmae* Zone) can be placed at the level of the lower part of the *Discus* Zone. In this case, the preceding *Infimum* Zone corresponds to the interval of the upper part of the *Orbis* Zone coupled with the lower part of the *Discus* Zone. Such a conclusion agrees with the scheme suggested by Callomon (Dietl and Callomon, 1988; Callomon, 1993), who correlated the *Calyx* Zone of eastern Greenland (correlative with the *Infimum* Zone) with the standard *Orbis* Zone.

Distribution. At present, the *M. jacquoti* Biohorizon is reliably recognized only in the Prosek-Isady section. However, it may be recognized in many other areas. For instance, this level probably corresponds to the lowermost part of the Callovian clays of the Volga region near Saratov (the Malinovyi Ravine), where *Macrocephalites (Macrocephalites)* cf. *triangularis* Spath (ex gr. *jacquoti*) was found (Repin and Rashvan, 1996). In 1998, I detected one specimen of *M. (M.) jacquoti* (Plate I, fig. 2) below the level of *Cadoceras (Paracadoceras)* cf. *elatmae* in the Pizhma River section of the Pechora River basin.

C. elatmae Biohorizon

Index species: *Cadoceras (Paracadoceras) elatmae* (Nikitin).

Nomenclature. The *C. elatmae* Biohorizon was recognized in the sections of Prosek-Isady (Fig. 2, assemblage **a4**), Uzhovka (Fig. 3, assemblage **b1**), Pezhenga (Fig. 4, assemblage **c1**), Manturovo-Znamenka, and Ivkino localities (Gulyaev and Kiselev, 1999; Gulyaev, 1999). In the Prosek-Isady section, none of ammonites was found in the interval separating the first occurrence level of *C. (P.) elatmae* from the level of the *M. jacquoti* assemblage.

Paleontological characteristics. Ammonites of the subfamily Cadoceratinae, the dominated *C. (P.) elatmae* (Plate II, fig. 4) included, represent more than 90% of the assemblage. Single specimens of *C. ("Bryocadoceras") simulans* Spath have extremely inflated shells with radial ribs curved sometimes backward. Microconchs of *Costacadoceras mundum* (Sas.) are smaller in size than the early forms of this genus. The biohorizon exhibits the maximal diversity of Macrocephalitinae species, which represent, however, only about 10% of the assemblage. The most common species is *Macrocephalites (Macrocephalites) volgae* Gul. (Plate VI, Fig. 1) with widely spaced and broad primary ribs. *M. (M.) prosekensis* Gul. [nom. nov. pro *M. (M.)* ex gr. *jacquoti* (Douv.), holotype (Gulyaev, 1999, p. 73, Plate I, Fig. 1)] is also frequently occurring. This form

seems to be a descendant of *M. (M.) jacquoti*; its ventral side is narrower and lateral ribs become smoothed at an earlier stage of development. The Prosek-Isady section also yielded a single specimen of *M. (Kamptokephalites?)* sp. juv.

Stratigraphic position. The *C. elatmae* Biohorizon approximately corresponds to the upper half of the lower third of the *Elatmae* Zone. In the scheme suggested, it overlies with a hiatus the *M. jacquoti* Biohorizon. The precise correlation of the *C. elatmae* Biohorizon to the standard scale is possible due to occurrence of some *Cadoceras* forms similar to *C. (P.) elatmae* from the lower part of the *Herveyi* Zone of Germany (Schwabia). These forms are *C. (P.) quenstedti* Spath (nom. nov. pro *Amm. sublaevis* Quenstedt, 1887, Plate 79, fig. 7) from the synonymous biohorizon in the middle part of the *Keppleri* Subzone and *C. (P.) suevicum* Call. *et al.* (nom. nov. pro *Amm. sublaevis macrocephali* Quenstedt, 1849, Plate 14, fig. 6; 1887, Plate 79, fig. 3), transient subspecies of which were found in the synonymous biohorizons situated in the upper part of the *Keppleri* Subzone, and also in the lower part of the *Terebratus* Subzone (Callomon *et al.*, 1988, 1989, 1992). As is noted by many specialists (Callomon *et al.*, 1988; Sei and Kalacheva, 1992, and others), *C. (P.) quenstedti* is very similar to *C. (P.) elatmae*, but *C. (P.) suevicum* seems to be indistinguishable from the latter. Accordingly, the *C. elatmae* Biohorizon is correlative with the *C. suevicum* α, β biohorizons of Germany.

Distribution: probably the same as that of the entire zone.

C. tschernyschewi Biohorizon

Index species: *Cadoceras (Bryocadoceras) tschernyschewi* Sokolov, 1912. The lectotype (Sokolov, 1912, Plate 1, fig. 2) is stored in the Chernyshev Geological Museum of St. Petersburg, no. 4/1370. The Tsil'ma River area.

Nomenclature. The *C. tschernyschewi* Biohorizon (Fig. 4, assemblage **c3**) is reliably established in the Pezhenga section only (Gulyaev, 1999).

Paleontological characteristics. Over 80% of the ammonite assemblage are represented by the subfamily Cadoceratinae. Shells of most common *C. (B.) tschernyschewi* (Plate III, fig. 1) are swollen to a various extent and show variably wide umbilici. Among these forms with relatively narrow umbilici, the extremely inflated variants resemble *Cadoceras* s.s., and the flattened ones are similar to *Cadochamoussetia* shells. In addition, the coexisting single *C. ("B.") aff. simulans* Spath differ from *C. ("B.") simulans*, as they have slightly narrower umbilicus and hardly noticeable ribbing bend in the middle of the ventral side of early whorls. Microconchs of Cadoceratinae are mainly represented by *Costacadoceras* sp nov. aff. *mundum* (Sas.), which have narrower ventral sides and more involute whorls than *C. mundum*. Representatives of the subfamily Gowericeratinae constitute approximately 10–15% of the assemblage. The biohorizon is proved to be marking the first occurrence of the subgenus *Kepplerites (Gowericeras)* represented by the archaic species *K. (G.) unzhae* Gul. (Plate VI, fig. 2), which retain dense ribbing on the mature body chamber (type feature of *Kepplerites* s.s.) but already has relatively broad whorls with well developed lateral spines (features of *Gowericeras* forms). Spines of this kind are also characteristic of microconchs *Toricellites pezhengae* (Gul.). The first occurrence of Pseudoperisphinctinae represented by sporadic *Homoeoplanulites* sp. ind. is also typical of the biohorizon.

Stratigraphic position. In the Pezhenga section, *C. (B.) tschernyschewi* was found above the level of *C. (P.) elatmae*. According to its morphology, it is the ancestor of *Cadochamoussetia surensis*. This enables positioning of the *C. tschernyschewi* Biohorizon between the *C. elatmae* and *C. surensis* biohorizons. The Prosek-Isady and Uzhovka sections of the Nizhnii Novgorod area yielded a similar form, which was identified as *C. (B.)* ex gr. *tschernyschewi* differing from the classic *C. (B.) tschernyschewi* in its narrower umbilicus. The form probably characterizes the *C. surensis* Biohorizon, However, its occurrence below the level of *C. surensis* is not improbable. The position of the *C. tschernyschewi* Biohorizon above the *C. elatmae* Biohorizon suggests its approximate correspondence to the middle part of the *Terebratus* Subzone.

Distribution. In Central Russia, the *C. tschernyschewi* Biohorizon is established in the northernmost Pezhenga section. Data on *C. (B.) tschernyschewi* finds in the lower Callovian beds near Saratov (Kamysheva-Elpat'evskaya *et al.*, 1956, 1959) are doubtful and may characterize a swollen variety of *C. (P.) elatmae*. The biohorizon may be distinguished in the Pechora River basin.

C. surensis Biohorizon

Index species: *Cadochamoussetia surensis* (Nikitin, 1985). The lectotype no. 36/1486, Sura River locality (Nikitin, 1985, Plate 10/12, no. 54) is stored at the Chernyshev Geological Museum (St. Petersburg).

Nomenclature. The *C. surensis* Biohorizon is distinct and well characterized by fauna in the Prosek-Isady (Fig. 2, assemblage **a5**) and Uzhovka (Fig 3, assemblage **b2**) sections, where it overlies, after an insignificant interval, the *C. elatmae* Biohorizon (Gulyaev and Kiselev, 1999; Gulyaev, 1999).

Paleontological characteristics. Almost 80% of the ammonite assemblage are represented by the subfamily Cadoceratinae, where dominant species is *C. surensis* (Plate IV, fig. 2). Although its shells are variably swollen, this species is generally close to the classic narrow-shell type. Single specimens of *Cadoceras (Bryocadoceras)* ex gr. *tschernyschewi* Sok. are characterized by inflated shell and moderately narrow

umbilicus. *C. (Paracadoceras)* cf. *primaevum* Sas. with slightly involute inner whorls is supposed to be found at this level of the Prosek-Isady section. Microconchs of Cadoceratinae are represented by *Costacadoceras* aff. *mundum* (Sas.), whose ventral side is narrower than that of *C. mundum*. The subfamily Gowericeratinae representing up to 10% of the ammonite assemblage includes species *Kepplerites (Gowericeras) unzhae* Gul. and *Toricellites pezhengae* (Gul.). In addition, the Uzhovka section yielded single forms with closer spaced ribs, which are tentatively identified as *K. (G.)* cf./aff. *unzhae*. The subfamily Macrocephalitinae constitutes only about 5% of the ammonite assemblage. It is represented by the peculiar species *Macrocephalites (Macrocephalites) pavlowi* Smor. (Plate II, fig. 3; Plate III, fig. 2), whose narrow shells are sharpening toward the ventral side of early whorls and have lateral sculpture smoothening at the early growth stage. About 10% of the ammonite assemblage belong to the subfamily Pseudoperisphinctinae represented by several species of the genus *Homoeoplanulites*.

Stratigraphic position. In the Uzhovka and Prosek-Isady sections of the Nizhnii Novgorod area, the ammonite assemblage of *C. surensis* Biohorizon succeeds the *C. elatmae* assemblage after a minor interval. Probably, this interval includes ammonites similar to *C. (B.) tschernyschewi*. The stratigraphic position of the *C. surensis* Biohorizon suggests its position approximately corresponding to the lower part of the *Kamptus* Subzone and, probably, to the uppermost interval of the *Terebratus* Subzone of the standard *Herveyi* Zone.

Distribution. The *C. surensis* Biohorizon is recognized in the Middle Volga region and adjacent areas.

C. subpatruus Biohorizon

Index species: *Cadochamoussetia subpatruus* (Nikitin, 1885). The holotype no. 38/1486 from the Sura River area (Nikitin, 1885, Plate (11) 13, fig. 58) is stored at the Chernyshev Geological Museum of St. Petersburg.

Nomenclature. The *C. subpatruus* Biohorizon is best manifested in the Uzhovka section (Fig. 3, assemblage **b3**), where it immediately overlies the *C. surensis* Biohorizon. Single specimens of *C. subpatruus* (Fig. 2, assemblage **a6**) were also found in the Prosek-Isady section (Gulyaev, 1999).

Paleontological characteristics. Nearly 75–80% of the ammonite assemblage are represented in the studied collections by the only species *C. subpatruus* of the subfamily Cadoceratinae (Plate III, fig. 3). This species marks the stage that resulted in appearance of *Chamoussetia* forms among Cadoceratinae. Within its stratigraphic range, *C. subpatruus* demonstrates a complete spectrum of morphological changes from the forms similar to *C. surensis* (Nik.) to those virtually indistinguishable from *Ch. (?) saratovensis* Call. et Wright. The subfamily Gowericeratinae represented by *Kepplerites (Gowericeras)* cf. *unzhae* Gul., whose relative abundance is approximately 10–15%. The subfamily Pseudoperisphinctinae (*Homoeoplanulites* sp. ind.) constitutes about 10% of the assemblage.

Stratigraphic position. The stratigraphic position of *C. subpatruus* Biohorizon suggests its approximate correlation with the middle part of the *Kamptus* Subzone of the standard *Herveyi* Zone.

Distribution. The *C. subpatruus* Biohorizon was reliably established only in middle courses of the Volga River.

Ch. saratovensis Biohorizon

Index species: *Chamoussetia (?) saratovensis* Callomon et Wright, 1989 (nom. nov. pro *Ch. chamousseti* (Sazonov, 1965, p. 38, Plate 9, Fig. 1). The holotype no. VI-146/28 from the Volga region near Saratov (Kamysheva-Elpat'evskaya *et al.*, 1956, p. 47, Plate 19, Fig. 57; 1959, p. 148, Plate 11, Fig. 5) is stored at the Vernadsky Geological Museum.

Nomenclature. The *Ch. saratovensis* Biohorizon can be recognized only in the Uzhovka section (Fig. 3, assemblage **b4**) (Gulyaev, 1999) above the *C. subpatruus* Biohorizon.

Paleontological characteristics. The subfamily Cadoceratinae represents approximately 75–80% of the ammonite assemblage. According to morphological characters, one macroconch *Ch. (?) saratovensis* (Plate IV, fig. 3) that was found can be referred to the genus *Chamoussetia* Douville. However, some archaic characters, such as slightly sharpened ventral side, absence of oppressed carina, and coarser sculpture persistent in ontogenesis, differ this species from representatives of the *Ch. chamousseti* (Orb.) group of the *Koenigi* Zone. At the same time, it is very similar to *Cadochamoussetia* forms. Microconchs of Cadoceratinae are represented by rare *Costacadoceras* (?) sp. ind. About 10–15% of the ammonite fauna are represented by *Kepplerites (Gowericeras)* ex gr. *toricelli* (Opp.) from the subfamily Gowericeratinae, and about 10% by *Homoeoplanulites* (?) sp. ind. from the subfamily Pseudoperisphinctinae.

Stratigraphic position. In the scheme suggested here, the *Ch. saratovensis* Biohorizon is placed at the top of the *Elatmae* Zone. The assemblage including *K. (G.) toricelli*, *Homoeoplanulites* spp., and other ammonites characterizes the lowermost *K. toricelli* Biohorizon of the lower Callovian *Koenigi* Zone in Germany (Schwabia) (Callomon *et al.*, 1988, 1989). On this basis, the *Ch. saratovensis* Biohorizon can be correlated, at least partially, to the lower beds of the standard *Koenigi* Zone. However, the low preservation degree of ammonites representing genera *Kepplerites* and *Homoeoplanulites* is an obstacle for their comparison with counterpart from Western Europe, where they may be younger than in Central Russia. The precise correlation is also complicated by the ambiguous position of

the lower boundary of the *Koenigi* Zone (Callomon *et al.*, 1988, 1989; Callomon, 1993). Until the moment when additional data will be available, the *Ch. saratovensis* Biohorizon should be included into the *Elatmae* Zone because of facies and paleontological affinity (Gulyaev, 1999).

Distribution. The *Ch. saratovensis* Biohorizon is established in the Middle Volga region. Finds of its index species suggest that this unit may extend into the Volga region near Saratov and adjacent areas.

Koenigi Zone

Index species: *Proplanulites (Proplanulites) koenigi* (Sowerby, 1820). The lectotype was chosen by Buckman in England (1921, p. 36) and pictured by Arkell (1956, Plate 37, fig. 4).

Nomenclature. The *Koenigi* Zone was distinguished in the lower Callovian deposits of England by Buckman (1913). Callomon (1955, 1964) considered this stratigraphic unit as the lower subzone of the *Calloviense* Zone. At present the lower Callovian of the standard West European scale is again subdivided into the *Herveyi, Koenigi,* and *Calloviense* zones. The *Koenigi* Zone includes the *Gowerianus, Curtilobus* and *Galilaeii* subzones (Callomon *et al.*, 1988; Page, 1989).

The nomenclature of the uppermost *Galilaeii* Subzone is doubtful. Oppel (1862) used name *Amm. galilaeii* for the form that was described by Orbigny (1847, Plate 162, figs. 10, 11) as *Amm. calloviensis* Sow. Later, the original photograph by Orbigny was published by Tintant (1963, Plate 21, fig. 1) under name *Sigaloceras calloviense*. However, specimen pictured by Buckman (1922, Plate 290), but not that described by Orbigny, was chosen by Page (1989) and other West European authors (probably, following him) as the lectotype of *K. (G.) galilaeii* (Opp.) under the name *Galilaeiceras galilaeii* (Opp.). As is correctly noted by Meledina (1987), this ammonite is essentially different from the original of Orbigny. In my opinion, it should be classified as *K. (G.) curtilobus* (Buckm.). In Fig. 7 (2) reproduced by Page (1989), *K. (G.) galilaeii* (Opp.) also differs from the "lectotype" of Buckman resembling instead *K. (G.) trichophorus* (Buckm.) intermediate in morphology between *K. (Gowericeras)* and *Sigaloceras* s.s.

In the Russian platform, the local *Kepplerites calloviensis–K. gowerianus* Zone was recognized long ago in the upper part of the lower Callovian deposits above the *Elatmae* Zone (*Resheniya...*, 1955, 1962; *Postanovlenie...*, 1978). Using the great similarity of ammonite faunas from Western Europe and Russian platform, Meledina (1986, 1987) proposed to apply the standard biozonation to the upper part of the lower Callovian in European Russia.

Paleontological characteristics. In contrast to the *Elatmae* Zone, the *Koenigi* Zone of Central Russia shows an increased percentage of forms of the subfamily Gowericeratinae and a noticeable amount of representatives of the subboreal subfamily Proplanulitinae.

The subfamily Cadoceratinae represents in average 40–50% of the ammonite assemblage. The subfamily mostly consists of species of the subgenus *Cadoceras* s.s. The genus *Chamoussetia* Douville is also characteristic of the zone, especially of its lower part. These groups are associated with relatively rare forms similar to *C. ("Bryocadoceras") laetum* Gul. (descendants of the *C. ("B.") simulans* group). Their last whorls resemble those of *Cadoceras* s.s., but the earlier growth stages are characterized by more inflated shell decorated with radial ribs slightly curved backward. Microconchs of Cadoceratinae are represented by subgenera *Pseudocadoceras (Pseudocadoceras)* Buckman and *P. (Novocadoceras)* Sasonov. Some evolute forms bear similarity to the genus *Costacadoceras* Rawson.

The subfamily Gowericeratinae is also an important component of the ammonite assemblages (40–50 and occasionally up to 70%). Its representatives *Kepplerites (Gowericeras)* Buckman [M] and *Toricellites* Buckman [m] gradually reshape into *Sigaloceras (Sigaloceras)* Hyatt [M] and *Gulielmina* Buckman [m] respectively, which are characteristic of the following *Calloviense* Zone.

Forms of the subboreal subfamily Proplanulitinae s.s. (including one genus *Proplanulites* Teisseyre) represent as much as 15–20% of the ammonite assemblage. The subfamily Pseudoperisphinctinae is represented in collections by single specimens of *Homoeoplanulites*.

In some publications (e.g., Lahuzen, 1883), there is doubtful statement that some forms of the subfamily Macrocephalitinae occur in the *Koenigi* Zone of Central Russia.

Stratigraphic position. The *Koenigi* Zone of Central Russia corresponds to the synonymous zone of the standard scale.

Distribution. The *Koenigi* Zone is recognized in the subboreal areas of Europe, eastern Greenland and Mangyshlak.

K. densicostatus Biohorizon

Index species: *Kepplerites (Gowericeras) densicostatus* Tintant, 1963. The holotype from the Poix site of France is reproduced by Tintant (1963, p. 141, Plate 15, Fig. 1).

Nomenclature. The *K. densicostatus* Biohorizon is best manifested in the Uzhovka section (Fig. 3, assemblage **b5**). It is also present in the Prosek-Isady section (Fig. 2, assemblage **a7**), and probably in the lower Callovian section at the Cheremukha River. *K. (G.) densicostatus* was also found at the Unzha River locality.

Paleontological characteristics. Slightly more than 40% of the ammonite assemblage of the Uzhovka section are represented by the subfamily Cadoceratinae, where *Chamoussetia chamousseti* (Orb.) s.l.

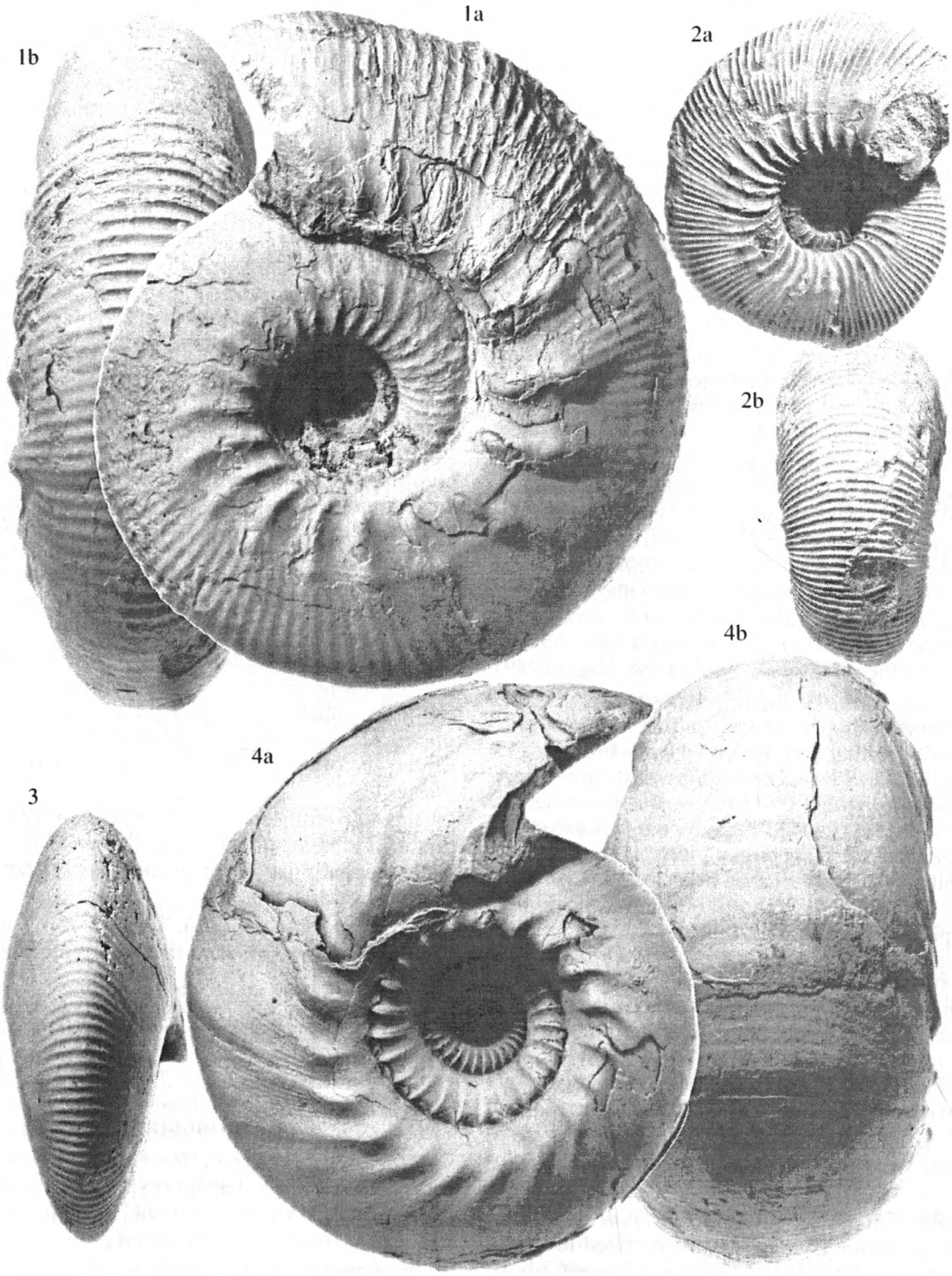


Plate II. Characteristic early Callovian ammonite species of Central Russia (full size)

(1) *Kepplerites (Gowericeras) curtilobus* (Buckman), no. 2/865: (1a) side view, (1b) ventral view; the Prosek-Isady section, *Koenigi* Zone, *K. curtilobus* Biohorizon. (2) *K. (G.) curtilobus* (Buckman), no. 2/857: (2a) side view, (2b) ventral side; the Prosek-Isady section, *Koenigi* Zone, *K. curtilobus* Biohorizon. (3) *Macrocephalites (Macrocephalites) pavlowi* Smorodina, no. A155 (283/5), ventral side; the Prosek-Isady section, *Elatmae* Zone, *C. surensis* Biohorizon (see Plate III, no. 2). (4) *Cadoceras (Paracadoceras) elatmae* (Nikitin), no. A76: (4a) side view, (4b) ventral view; the Prosek-Isady section, *Elatmae* Zone, *C. elatmae* Biohorizon.

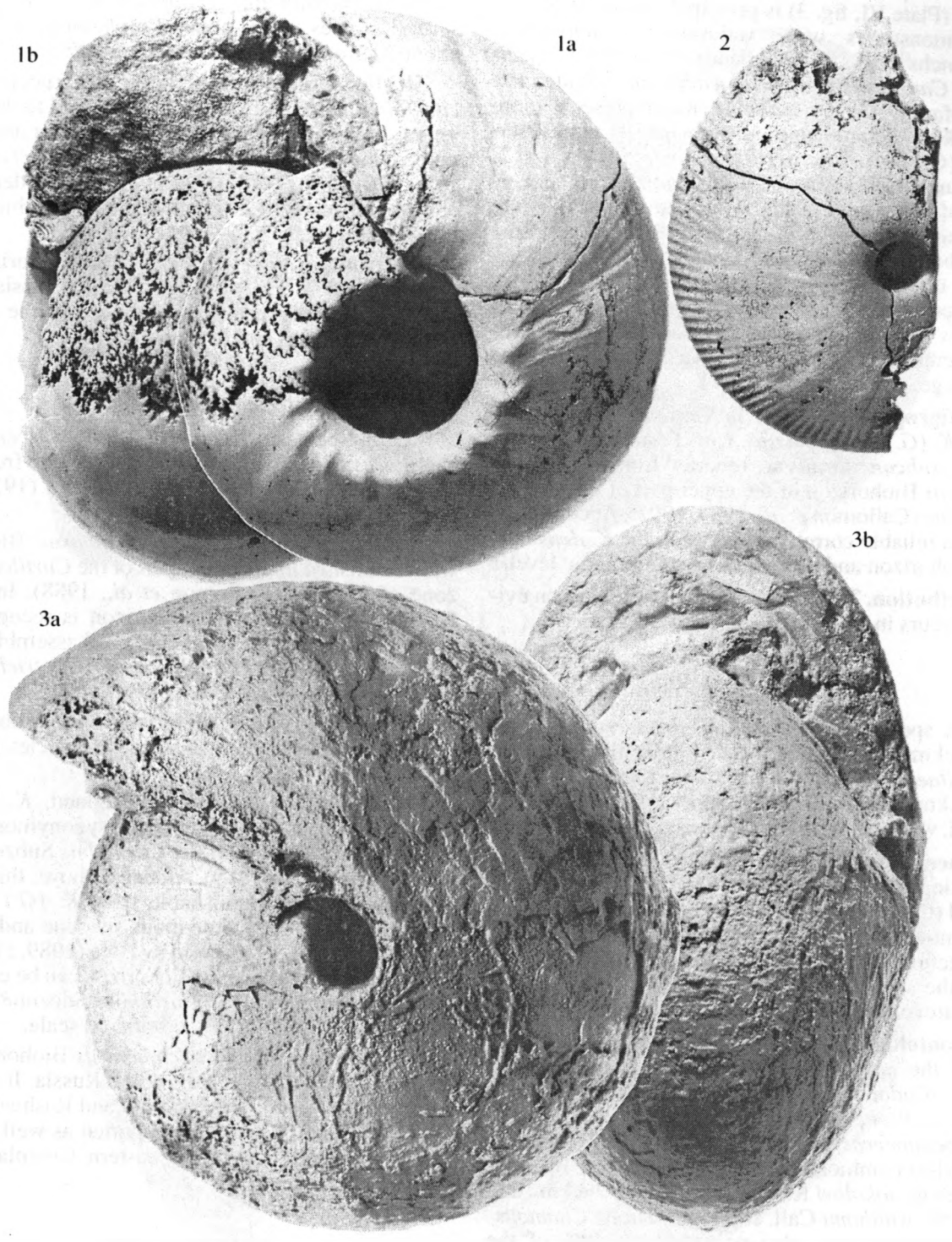


Plate III. Characteristic early Callovian ammonite species of Central Russia (full size)
(1) *Cadoceras (Bryocadoceras) tschernyschewi* Sokolov, no. 3/587: (1a) side view, (1b) apertural view; the Pezhenga section: *Elatmae* Zone, *C. tschernyschewi* Biohorizon. (2) *Macrocephalites (Macrocephalites) pavlowi* Smorodina, no. A155 (283/5), side view; the Prosek-Isady section, *Elatmae* Zone, *C. surensis* Biohorizon (see Plate II, no. 3). (3) *Cadochamoussetia subpatruus* (Nikitin), no. 5/1159: (3a) side view, (3b) view from the mouth; the Uzhovka section, *Elatmae* Zone, *C. subpatruus* Biohorizon.

[?=*Ch. phillipsi* Call. et Wright, *Ch. buckmani* Call. et Wright] (Plate VI, fig. 3) is principal dominant species that demonstrates wide variations. *Chamoussetia* microconchs occur in abundance. In contrast, specimens of *Cadoceras* and *Pseudocadoceras* s.s. are rare. The subfamily Gowericeratinae also represents more than 40% of the ammonite assemblage. Its representatives *K. (G.) densicostatus* (Plate I, fig. 3; Plate V, fig. 2) are distinct from forms of the subgenus *K. (Gowericeras)* of the *Elatmae* Zone, as they have more involute whorls and wider spaced, coarser primary ribs on the mature body chamber. Microconchs of Gowericeratinae are represented by *Toricellites lahuseni* (Par. et Bon.). Species *Proplanulites (Proplanulites)* cf. *subcuneiformis* Buckm. and others of the subfamily Proplanulitinae constitute approximately 15% of the ammonite assemblage.

Stratigraphic position. In Germany (Schwabia), species *K. (G.) densicostatus, Ch.* cf./ aff. *phillipsi* and *P. (P.)* cf. *subcuneiformis* are reported from the *M. macrocephalus* Biohorizon of the upper part of the *Gowerianus* Zone (Callomon *et al.*, 1989, 1992). Accordingly, there is a reliable correlation between the *K. densicostatus* Biohorizon and this standard stratigraphic level.

Distribution. The *K. densicostatus* Biohorizon evidently occurs in many areas of Central Russia.

K. curtilobus Biohorizon

Index species: *Kepplerites (Gowericeras) curtilobus* (Buckman, 1922) [=*K. (G.) crucifer* (Buckm.), ? *K. (G.) galilaeii* (Opp.) sensu Buckman, ? *K. (G.) indigestus* (Buckm.)]. Photograph of holotype from Yorkshire, England, was published by Buckman (1922, Plate 294).

Nomenclature. The *K. curtilobus* Biohorizon was first distinguished at the base of the *Curtilobus* Zone of England (Callomon *et al.*, 1988). In Central Russia, the synonymous biohorizon was recognized in the Prosek-Isady section (Fig. 2, assemblage **a8**) (Gulyaev, 1999) and in the sections of Alpat'evo (Fig. 5, assemblage **d1**), Akatovo, and Manturovo-Znamenka sites.

Paleontological characteristics. Approximately 40% of the ammonite fauna are constituted by the diverse *Cadoceras (Cadoceras), C. ("Bryocadoceras"), Pseudocadoceras (Pseudocadoceras)*, and *P. (Novocadoceras)* species of the subfamily Cadoceratinae. Most common forms are *C. (C.) tolype* Buckm., *C. (C.)* ex gr. *sokolovi* Kiss, *P. (P.) boreale* Buckm., and *P. (P.?)* aff. *whithami* Call. et Wright. Single *Chamoussetia* specimens may also occur. About 40% of the ammonite assemblage are represented by the species *K. (G.) curtilobus* (Plate II, figs. 1, 2) and *Toricellites curticornutus* Buckm. of the subfamily Gowericeratinae. These species marks the next evolutionary stage of the genus *Kepplerites*. The former differs from the index species of the preceding biohorizon by its more involute and higher whorls, finer and closer spaced ribs at the early and intermediate growth stages, and by widely spaced and thick primary ribs on the mature body chamber. The subfamily Proplanulitinae represented by several species of the genus *Proplanulites* constitutes about 20% of the ammonite assemblage.

Stratigraphic position. In England, species *K. (G.) curtilobus* and *C. (C.) tolype* are confined to the synonymous biohorizons established in the lower and middle parts of the *Curtilobus* Subzone (Callomon *et al.*, 1988, 1989; Page, 1989). Thus, the biohorizon under consideration can be correlated with this stratigraphic level of the standard scale.

Distribution. The *K. curtilobus* Biohorizon was distinguished in England and Central Russia. Found index species suggests its occurrence in the south of European Russian and in Mangyshlak.

K. trichophorus Biohorizon

Index species: *Kepplerites (Gowericeras) trichophorus* (Buckman, 1922). The holotype from Yorkshire, England, is pictured by Buckman (1922, Plate 291).

Nomenclature. The *K. trichophorus* Biohorizon was established in the upper part of the *Curtilobus* Subzone of England (Callomon *et al.*, 1988). In Central Russia, the synonymous biohorizon is recognized in the Prosek-Isady section (Fig. 2, assemblage **a9**) (Gulyaev, 1999). Specimens of *K. (G.) trichophorus* were also found at the Unzha River.

Paleontological characteristics. The biohorizon is reliably characterized only by the index species. (Plate IV, fig. 1).

Stratigraphic position. In England, *K. (G.) trichophorus* is mainly typical of the synonymous biohorizon in the upper part of the *Curtilobus* Subzone (Callomon *et al.*, 1988, 1989). As stated above, this species seems to be indistinguishable from *K. (G.) galilaeii* recovered from the synonymous subzone and biohorizon of Wiltshire and pictured by Page (1989, Fig. 7 (2)). Thus, the *K. trichophorus* Biohorizon can be correlated with the upper part of the *Curtilobus* Subzone and with the *Galilaeii* Subzone of the standard scale.

Distribution. The *K. trichophorus* Biohorizon was recognized in England and Central Russia. It may also be present in Mangyshlak (Repin and Rashvan, 1996). *K. (G.)* cf. *trichophorus* was reported as well from the *Ch. phillipsi* Biohorizon of eastern Greenland (Callomon, 1993).

Calloviense Zone

Index species: *Sigaloceras (Sigaloceras) calloviense* (Sowerby, 1815). The lectotype was chosen in England and described by Arkell (1933, Plate 36, fig. 5).

Nomenclature. The *Calloviense* Zone was initially distinguished by Oppel (1857) as a peculiar upper interval of the *Amm. macrocephalus* Beds of England (approximately the entire lower Callovian Substage).

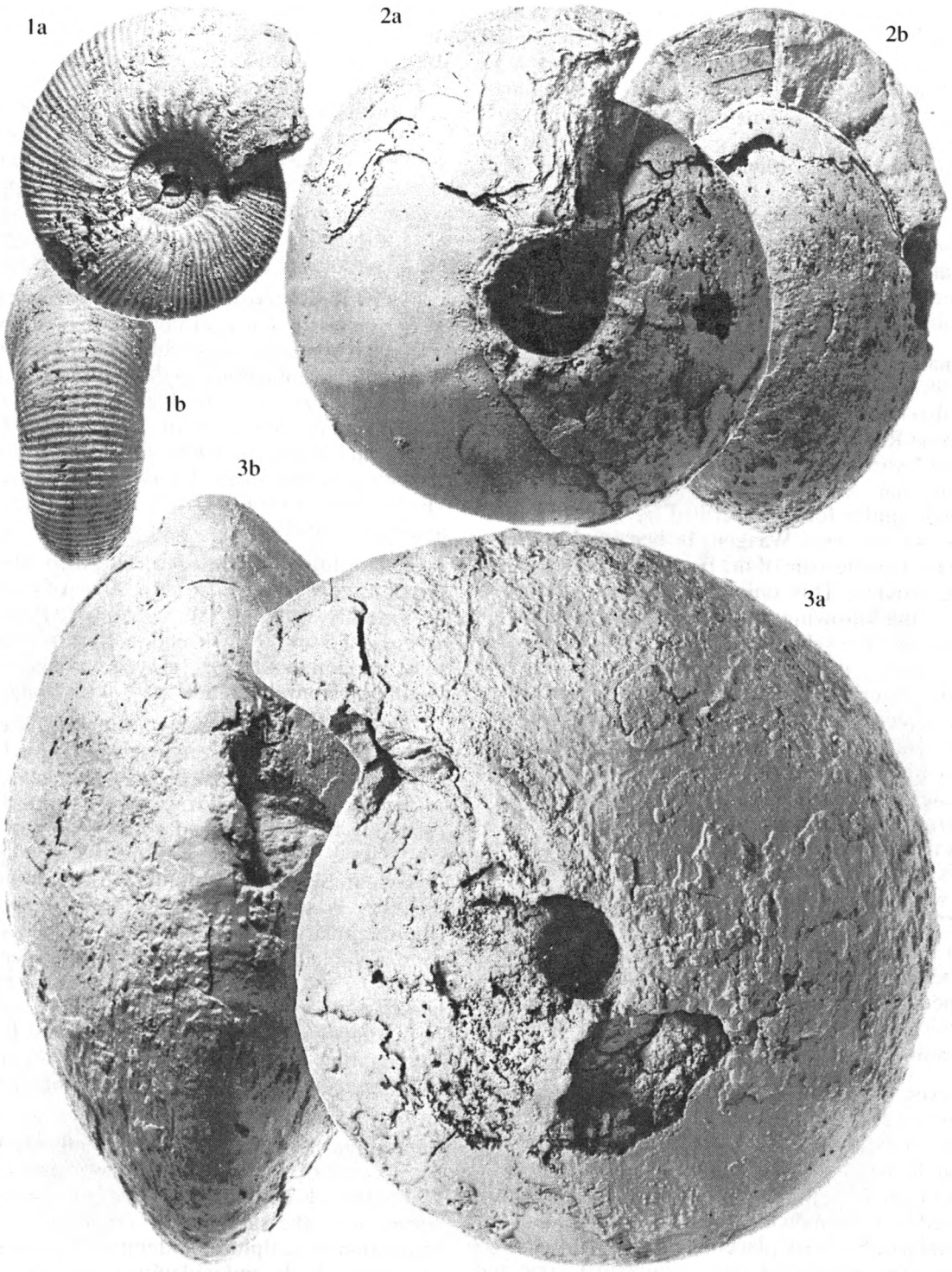


Plate IV. Characteristic early Callovian ammonite species of Central Russia (full size)
(1) *Kepplerites (Gowericeras) trichophorus* (Buckman), no. A10: (1a) side view, (1b) ventral side); the Prosek-Isady section, *Koenigi* Zone, *K. trichophorus* Biohorizon. (2) *Cadochamoussetia surensis* (Nikitin), no. A132: (2a) side view, (2b) apertural view; the Prosek-Isady section, *Elatmae* Zone, *C. surensis* Biohorizon. (3) *Chamoussetia (?) saratovensis* Callomon et Wright, no. 5/1142: (3a) side view, (3b) ventral view; the Uzhovka section, *Elatmae* Zone, *Ch. saratovensis* Biohorizon.

The *Calloviense* Zone was subdivided by Callomon (1955) into three subunits: the lower subzone equivalent to the *Koenigi* Zone established by Buckman (1913), the middle nominal subzone, and the upper *Planicerclus* Subzone. Later Callomon (1964) came to the conclusion that the forms described by Buckman (1923) as *Sigaloceras (Catasigaloceras) planicerclus, S. (C.) crispatum*, and *S. (C.) curvicerclus* from the Callovian deposits of England are synonyms of *S. (C.) enodatum* (Nikitin, 1881) from Central Russia. This allowed him to rename the *Planicerclus* Zone into the *Enodatum* Zone.[1] At present the *Koenigi* Zone is authorized as an independent unit, and the standard *Calloviense* Zone is subdivided into the *Calloviense* and *Enodatum* subzones (Callomon *et al.*, 1988; Page, 1989).

By analogy with the standard zonation, Meledina (1986, 1987) suggested to distinguish the *Calloviense* Zone (Subzone) in the upper part of the lower Callovian of European Russia. However, she did not consider the *Enodatum* Subzone as the terminal subdivision of the lower Callovian. She included the species *S. (C.) enodatum* and similar forms described by Buckman into the genus *Kosmoceras* Waagen. In her opinion, these species are characteristic of the basal *Jason* Zone of the middle Callovian. This opinion is hardly acceptable because of the following reasons. (1) None of specialists doubts that the subgenus *Sigaloceras (Catasigaloceras)*, including the species under discussion and its synonyms described by Buckman, is intermediate between *Sigaloceras* s.s. and *Kosmoceras (Gulielmites)*. In practice, taxonomy of such intermediate groups is frequently defined by tradition (when other facts of the case are equal). (2) The phyletic succession *Sigaloceras* s.s.–*S. (Catasigaloceras)*–*K. (Gulielmites)* suggests that *S. (C.) enodatum* appeared earlier than its ancestors *K. (G.) medea* (Call.) and *K. (G.) jason* (Rein.), which are subzonal index species in the *Jason* Zone (Callomon, 1955). (3) In the Alpat'evo and Nikitino sections, *S. (C.) enodatum* was actually found below the levels with the mentioned middle Callovian index species. Thus, it is obvious that the *Enodatum* and *Jason* zones should not be considered as stratigraphic units of the same level.

However, the problem of the lower–middle Callovian boundary is still unsolved. The *Kepplerites enodatum* Zone was originally distinguished by Sazonov (1953) in the basal middle Callovian of European Russia earlier than the synonymous subzone independently recognized by Callomon at the top of the lower Callovian in England. Sazonov placed the *Kepplerites enodatum* Zone above the *Kepplerites calloviensis* Zone and below the *Kosmoceras jason* Zone, i.e., at its present level in Western Europe. The substage boundaries in the current standard scale of the Callovian were established by Callomon (1955), who noted that (1) they mark significant faunal changes and (2) virtually coincide with the boundaries initially recognized by Oppel. In both scales, the suggested position of the lower–middle Callovian boundary is not indisputable. It is difficult to evaluate objectively the faunal changes at the upper and lower boundaries of the *Enodatum* Zone because the defined taxonomic affiliation of the index species is subjective. The boundary between the *Amm. macrocephalus* and *Amm. anceps* zones of Oppel (1857), which approximately correspond to the lower and middle Callovian, respectively, seems also uncertain from the standpoint of recent detailed subdivision.

Thus, if we consider "the triad of Arkell" (Arkell, 1946) as basic for positioning of the lower–middle Callovian boundary, the criteria of *priority* and *suitability* would be ambiguous, and we should be guided only by the last criterion of *usage*. Since the majority of researchers (Callomon *et al.*, 1988, 1989; Page, 1989; Repin and Rashvan, 1996; *Biostratigraphie...*, 1997; and others) consider the *Enodatum* Subzone as a subdivision of the lower Callovian, I support their opinion to avoid contradictions.

Paleontological characteristics. In contrast to the previous zone, the *Calloviense* Zone of Central Russia is virtually lacking the subfamily Proplanulitinae, whereas the subfamily Pseudoperisphinctinae turns out to be the dominant group in its ammonite assemblages beginning from the middle part of the zone.

Most significant in many ammonite assemblages is the subfamily Gowericeratinae represented by species of the genus *Sigaloceras* Hyatt, which have, in contrast to the ancestral *Kepplerites (Gowericeras)* forms, the relatively high fine-ribbed whorls and narrow umbilicus. These species are lacking the developed lateral spines, and primary sculpturing of their mature body chamber is strongly reduced, sometimes completely (the secondary sculpture of younger forms is reduced as well). Macroconchs of Gowericeratinae are represented by the subgenus *S. (Sigaloceras)* in the lower part of the zone and by *S. (Catasigaloceras)* Buckman in the upper one. Shells of the latter are flattened and smaller, thus being similar to shells of the middle Callovian subgenus *Kosmoceras (Gulielmites)* Buckman.

The subfamily Cadoceratinae is widespread throughout the zone. Its macroconchs are represented by species of the subgenus *Cadoceras (Cadoceras)* Fisher, which demonstrate the gradual morphological transition to the subgenus *C. (Rondiceras)* Troitskaya (reduction of sculpture, flattening of increasingly involute early whorls, and widening of umbilicus at the later growth stages). Less frequent forms are representatives of *C. ("Bryocadoceras")* (descendants of the group of *C. ("B.") laetum* Gul.) having wide whorls with radial ribs. Among two microconch groups of Cadoceratinae, the first one is represented by flattened involute and finely ribbed species of *Pseudocadoceras (Pseudocadoceras)* Buckman, and the second by moderately evo-

[1] The *Enodatum* Zone was first mentioned by Brinkmann (1929). However, Callomon (1964) stressed that Brinkmann applied terms *zone* and *subzone* to stratigraphic ranges of individual species distinguishing as many as five zones in some sequences.

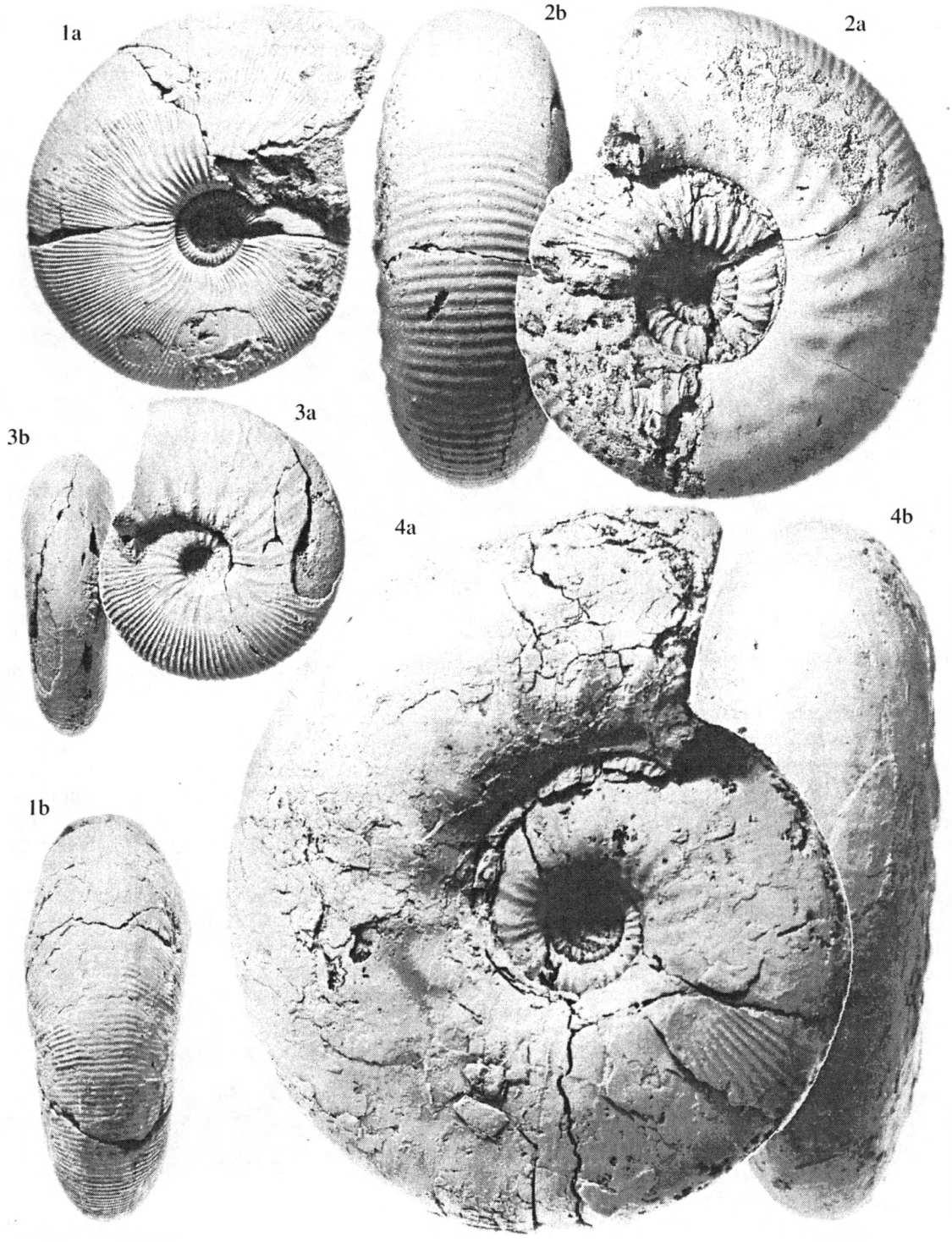


Plate V. Characteristic early Callovian ammonite species of Central Russia (full size)

(1) *Sigaloceras (Sigaloceras) calloviense* (Sowerby), no. A60: (1a) side view, (1b) ventral view; the Prosek-Isady section, *Calloviense* Zone, *S. calloviense* Biohorizon. (2) *Kepplerites (Gowericeras) densicostatus* Tintant, no. A35: (2a) side view, (2b) ventral side; the Prosek-Isady section, the *Koenigi* Zone, the *K. densicostatus* Biohorizon. (3) *Sigaloceras (Catasigaloceras) enodatum* (Nikitin), no. 7/1250: (3a) side view, (3b) ventral side; the Nikitino section, *Calloviense* Zone, *S. enodatum* Biohorizon. (4) *S. (Sigaloceras) calloviense* (Sowerby), no. A53: (4a) side view, (4b) ventral view; the Prosek-Isady section, *Calloviense* Zone, *S. calloviense* Biohorizon.

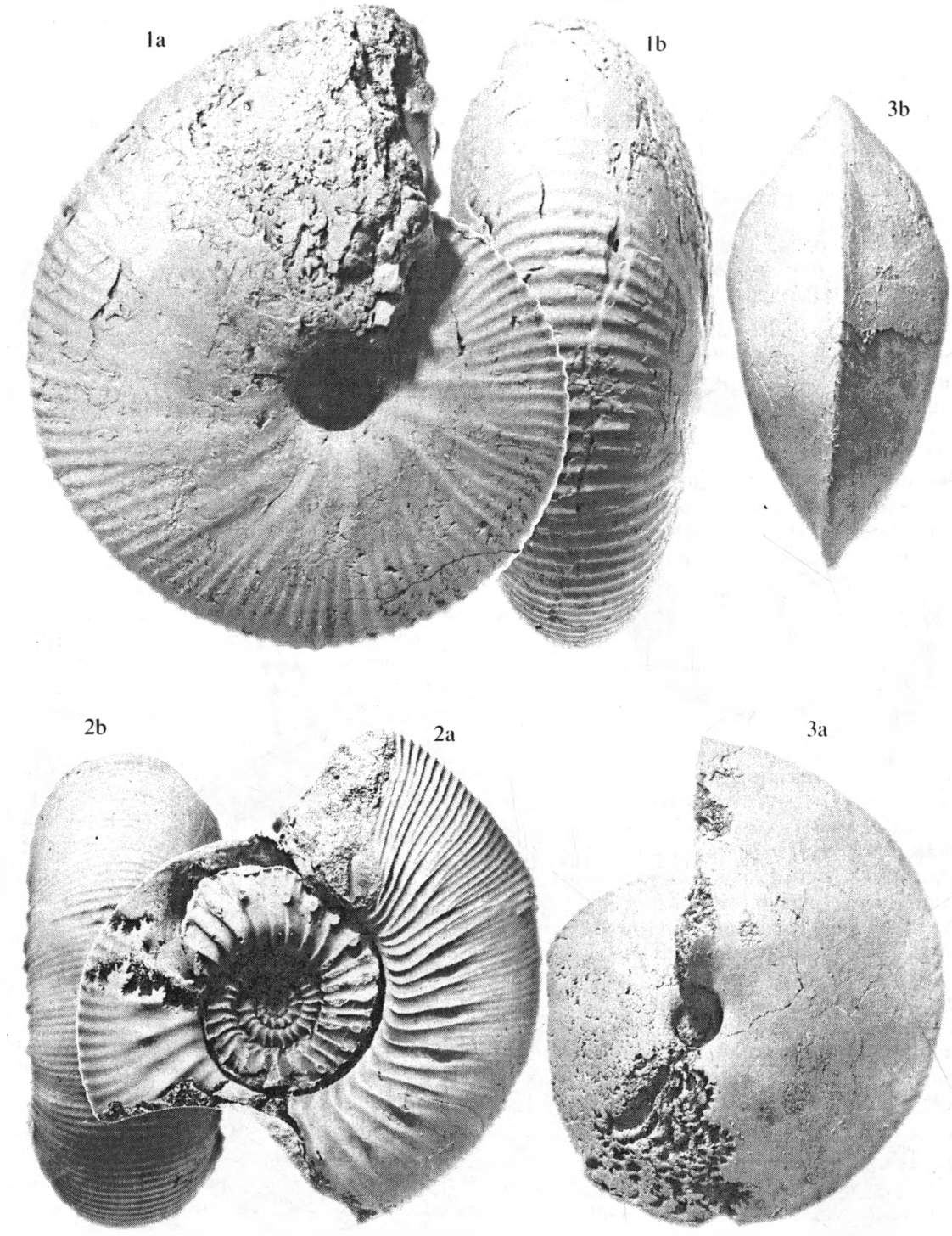


Plate VI. Characteristic early Callovian ammonite species of Central Russia (actual size)
(1) *Macrocephalites (Macrocephalites) volgae* Gulyaev, holotype no. 2/1241 (283/3): (1a) side view, (1b) ventral view; the Prosek-Isady section, *Elatmae* Zone, *C. elatmae* Biohorizon. (2) *Kepplerites (Gowericeras) unzhae* Gulyaev, holotype no. 3/1007 (283/7): (2a) side view, (2b) ventral side; the Pezhenga section, the *Elatmae* Zone, the *C. tschernyschewi* Biohorizon. (3) *Chamoussetia chamousseti* (Orbigny), no. A124: (3a) side view, (3b) ventral view; the Prosek-Isady section, *Koenigi* Zone, *K. densicostatus* Biohorizon.

lute and coarsely ribbed species of *P. (Novocadoceras)* Sasonov.

The lower part of the zone yields rare younger representatives of the subfamily Proplanulitinae (*Proplanulites (Crassiplanulites)* Buckman), while the upper one bears a noticeable amount of *Homoeoplanulites (Anaplanulites)* Buckman, *Indosphinctes* Spath, and *Choffatia* Siemiradzki forms representing the subfamily Pseudoperisphinctinae.

Stratigraphic position. The *Calloviense* Zone of Central Russia corresponds to that of the standard scale.

Distribution. The *Calloviense* Zone is recognized in subboreal areas of Europe, eastern Greenland, and eastern Caspian Lowland.

S. calloviense Biohorizon

Index species: *Sigaloceras (Sigaloceras) calloviense* (Sowerby).

Nomenclature. The *S. calloviense* Biohorizon was distinguished at the base of the *Calloviense* Zone in England (Callomon *et al.*, 1988). In Central Russia, it was established in the sections of Prosek-Isady (Fig. 2, assemblage **a10**) (Gulyaev, 1999), Alpat'evo (Fig. 5, assemblage **d2**), Manturovo-Znamenka, Ivkino, and Nikitino localities.

Paleontological characteristics. Nearly 60–70% of the ammonite assemblage are represented by *S. (S.) calloviense* (Plate V, figs. 1, 4) and *Gulielmina quinqueplicata* Buckm. species of the subfamily Gowericeratinae. The subfamily Cadoceratinae is frequently next in abundance. Macroconchs are dominated by forms similar to *Cadoceras (Cadoceras) sublaeve* (Sow.) and associated with rare shells of *C. ("Bryocadoceras")* cf./aff. *laetum* Gul. The Cadoceratinae microconchs are represented by several of *Pseudocadoceras* s.s. and *P. (Novocadoceras)* species, and also by ammonites similar in morphology to *Costacadoceras* forms. The subfamily Proplanulitinae including rare *Proplanulites (Crassiplanulites)* sp. is a minor component of the ammonite assemblage.

Stratigraphic position. In England, species *S. (S.) calloviense* and *C. (C.) sublaeve* are confined to the *S. calloviense* Biohorizon of the lower part of the *Calloviense* Subzone (Callomon *et al.*, 1988; Page, 1989). This correlates the biohorizon under consideration with the respective stratigraphic level of the standard zonation.

Distribution. According to the index species finds, the distribution of the *S. calloviense* Biohorizon is as that of the entire zone.

S. enodatum Biohorizon

Index species: *Sigaloceras (Catasigaloceras) enodatum* (Nikitin, 1881) [=*S. (C.) crispatum* (Buckm.), *S. (C.) curvicerclus* (Buckm.), ? *S. (C.) planicerclus* (Buckm.)]. The lectotype no. 26/1344 from the Elat'ma locality at the Oka River (Nikitin, 1881, Plate 10 (3), figs. 12, 13) is stored in the Chernyshev Geological Museum of St. Petersburg.

Nomenclature. The *S. enodatum* α, β, and γ biohorizons were established in the *Enodatum* Subzone of England (Callomon *et al.*, 1988; Page, 1989). In Central Russia, the *S. enodatum* Biohorizon was recognized in the Alpat'evo (Fig. 5, assemblage **d3**) and Nikitino sections.

Paleontological characteristics. The ammonite assemblages are usually dominated by extremely variable macroconchs *S. (C.) enodatum* (Plate V, fig. 3) and by microconchs *Gulielmina (?) anterior* (Brinkm.) from the subfamily Gowericeratinae. The subfamily Pseudoperisphinctinae is also abundant and frequently prevailing in the assemblages. Forms similar to *Homoeoplanulites (Anaplanulites) difficilis* (Buckm.) were found as well. In the Nikitino and Alpat'evo sections, this biohorizon also yielded *Indosphinctes (Indosphinctes)* spp. and *Choffatia (Choffatia)* spp. The subfamily Cadoceratinae is usually less abundant than other groups. In the Nikitino section, macroconchs of this family are mainly represented by forms similar to *Cadoceras (Cadoceras?) tschefkini* (Orb.) and to *C. (Rondiceras) milaschevici* (Nik.). The Cadoceratinae microconchs are classed with *Pseudocadoceras (Pseudocadoceras) homoeomorphum* Kiss. and *P. (Novocadoceras* cf. *suraense* (Sas.).

Stratigraphic position. According to succession of transient varieties of the index species, several biohorizons with *S. (C.) enodatum* were recognized in the *Enodatum* Subzone of England. In Central Russia, the undivided *S. enodatum* Biohorizon is considered as an analogue of the entire synonymous subzone of the standard zonation.

Distribution. Outside eastern Greenland, the *S. enodatum* Biohorizon (biohorizons) has almost the same distribution range as the synonymous zone.

CONCLUSIONS

Analysis of vertical ranges of ammonite taxa in some Middle Jurassic sections of the Nizhnii Novgorod, Moscow, and Yaroslavl areas revealed the successive faunal (species) assemblages stratigraphically corresponding to biohorizons. This was used to work out the detailed infrazonal scale for the upper Bathonian–lower Callovian of Central Russia. The indicated stratigraphic interval comprises four zones and 13 biohorizons, most of which are well correlative with the standard units of Western Europe.

The lowermost *Infimum* Zone includes the *C. infimum* and *C.* cf./aff. *infimum* biohorizons. This zone marks an earliest formation stage of the East European sea that represented an Arctic bay at that time. Ammonite assemblages of the zone contain only boreal taxa (Cadoceratinae and Gowericeratinae). The sharp geo-

graphic differentiation of ammonite faunas is an obstacle for the direct correlation of the *Infimum* Zone with the standard scale. According to its stratigraphic position relative the *Elatmae* Zone, the zone in question must correspond approximately to the *Discus* Zone and, probably, to an upper part of the *Orbis* Zone of the standard upper Bathonian zonation.

The next *Elatmae* Zone includes *M. jacquoti, C. elatmae, C. tschernyschewi, C. surensis, C. subpatruus*, and *Ch. saratovensis* biohorizons. The lower boundary of the zone is dated by the time, when the East European basin became connected with the Tethyan seas and developed under subboreal conditions. Boreal elements (Cadoceratinae and Gowericeratinae) dominant in the ammonite assemblages are combined with representatives of Tethyan taxa (Macrocephalitinae and Pseudoperisphinctinae). Basing on correlation of some stratigraphic levels, the *Elatmae* Zone as a whole is considered to be analogous to the lowermost *Herveyi* Zone of the standard Callovian scale.

The *Koenigi* Zone includes *K. densicostatus, K. curtilobus*, and *K. trichophorus* biohorizons. The zone marks widening connections of the East European basin with the West European seas. The low-boreal (Gowericeratinae) and subboreal (Proplanulitinae) taxa, along with the high-boreal (Cadoceratinae) groups, become significant components of the ammonite assemblages of that time. The *Koenigi* Zone of Central Russia corresponds to the same standard zone.

The *Calloviense* Zone crowning the lower Callovian zonation includes the *S. calloviense* and *S. enodatum* biohorizons. Like the preceding zone, it corresponds to the time of widening connections between the East and West European basins. The low-boreal (Gowericeratinae) and Pan-Tethyan (Pseudoperisphinctinae) taxa became important components of the respective ammonite assemblages. The *Calloviense* Zone of Central Russian corresponds to the same zone of the standard scale.

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Late Pleistocene–Holocene Benthic Foraminifers and Evolution of Near-Bottom Environments in the Central Sea of Okhotsk

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Abstract—Taxonomic composition and distribution of benthic foraminifers in the upper Pleistocene–Holocene sediments that are penetrated by the gravity core in the southern slope of the Akademii Nauk Rise in the central part of the Sea of Okhotsk (Station V34-90) are discussed. Four established assemblages of benthic foraminifers successively replacing each other upward in the section reflect relevant stages of hydrological evolution of the basin: the terminal stage of the last glacial (2000–12500 years ago), deglaciation stage (12500–8500 years ago), and the early (8500–4000 years ago) and late (the last 4000 years) phases of the current interglacial. A comparison between foraminiferal assemblages from the Akademii Nauk Rise and from coeval sediments studied before in the southeastern part of the Sea of Okhotsk revealed that the near-bottom environments during both the deglaciation and current interglacial periods differed in these areas. It is assumed that these regional differences point to the time-variable influence of the Pacific warm water.

Key words: benthic foraminifers, late Pleistocene, Holocene, glacial, deglaciation, interglacial, Sea of Okhotsk.

INTRODUCTION

Benthic foraminifers occurring almost everywhere in marine and oceanic sedimentary sequences serve as a reliable tool for reconstruction of bottom environments in the past basins. Their distribution in modern oceans is generally classed with three types of zoning: curcumcontinental, bathymetrical, and climatic (Saidova, 1975). Similar patterns are also characteristic of marginal seas, although foraminiferal distribution there is more complicated being controlled by many interrelated factors. Most important of the latter are the temperature and chemical characteristics of bottom water and also the content of nutrients in sediments and water. All these characteristics depend on different parameters of the given sea basin (geographical position, dimensions, degree of isolation, depth, bottom morphology, and others), as well as on the structure of surrounding land and on processes influencing the latter. Hence, the study of benthic foraminifers in sedimentary successions of marginal sea basins makes it possible to reconstruct environments within the basin and to trace environmental changes on the adjacent continent.

Such investigations are particularly important for reconstruction of climatic and hydrological evolution during the Quaternary, when alternating glacial and interglacial periods controlled composition of foraminiferal assemblages. Most adequate reconstructions are possible for the basins, where ecological parameters of the modern benthic foraminiferal community close in composition to fossil assemblages are sufficiently well studied.

A good example is the Sea of Okhotsk characterized by peculiar hydrological conditions. An active circulation of water masses controls there an extremely high phytoplankton productivity in the surface water layer (Arzhanova and Zubarevich, 1997; Venttsel', 1997; Sorokin, 1997) and accumulation of biogenic-siliceous bottom sediments enriched in organic matter (Bezrukov, 1960). Sediments of the Sea of Okhotsk enclose diverse assemblages of benthic (secretory and agglutinated) and planktonic foraminifers, which allow different ecological parameters to be reconstructed for both the bottom and surface water layers. Taking into consideration that the Sea of Okhotsk was characterized by extremely high sedimentation rates, paleoenvironmental changes recorded in sedimentary sequences can be reconstructed in detail. Moreover, the high-latitude position of the sea alleviates solution of this problem, because climatic fluctuation and changes in its hydrological regime during glacial and interglacial periods were highly contrasting and, thus, distinctly recorded in composition of the planktonic and benthic biota.

The previous study on benthic foraminifers from the upper Quaternary sediments in the southeastern part of the Sea of Okhotsk showed that during the last 17000 years, its bottom was populated there by three assemblages replacing each other upward in the section and reflecting successive changes of glaciation, deglacia-

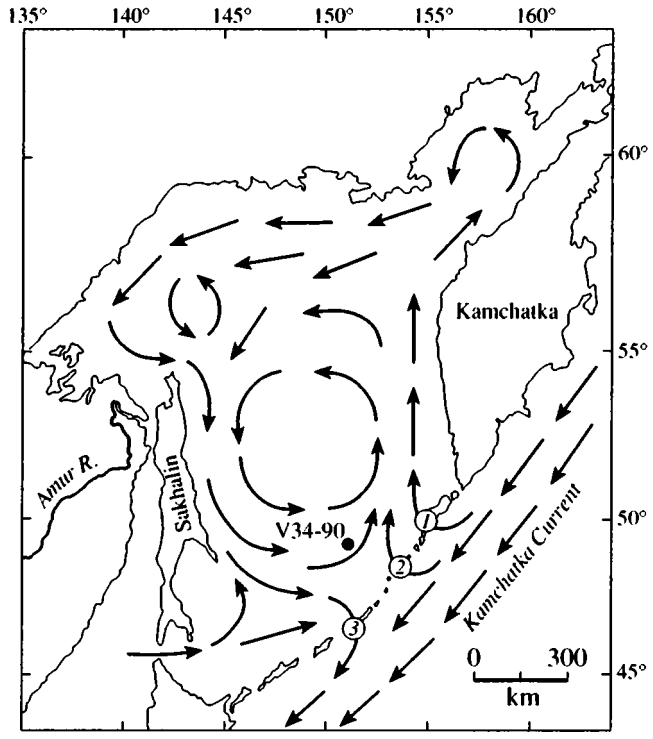

Fig. 1. Location of Station V34-90 in the Sea of Okhotsk. Encircled numbers: (*1*) Chetvertyi Kuril'skii Strait; (*2*) Kruzenshtern Strait; (*3*) Bussol' Strait.

tion, and post-deglaciation (or current interglacial) environments (Khusid and Basov, 1999).

In this paper, we discuss composition and distribution of benthic foraminifers in the upper Pleistocene–Holocene sediments of the central Sea of Okhotsk.

MATERIALS AND METHODS

Samples from Core V34-90 obtained during Leg 34 of R/V *Vulkanolog* to the southeastern slope of the Akademii Nauk Rise (48°49.9′ N; 150°27.6′ W) served as a material for this study. The core was taken from the depth of 1590 m (Fig. 1).

In the modern hydrological structure of the Sea of Okhotsk, waters in the study area are transitional between the bottom water of the deep South Kuril Basin, where temperature is about 1.8°C, and the warmer (up to 2.5°C), so-called Pacific deep water mass with the low content of dissolved oxygen (0.5–0.8 ml/l). The latter is formed within the intermediate depth range in the northern Pacific, from which it penetrates into the Sea of Okhotsk via the Chetvertyi and Kruzenshtern straits crossing the northern part of the Kuril island arc to spread further over the entire sea in the depth interval of 200 to 2000 m. The Pacific water mass is overlain by surface waters. In the spring–summer period, this mass consists of the surface water layer proper (upper 30–40 m thick), where the temperature sometimes amounts to 10°C or more, and the Sea of Okhotsk water mass. The latter spreads over the entire sea in the depth interval of 30–40 to 150–200 m and is characterized by low, sometimes negative temperatures (Moroshkin, 1966; D'yakov *et al.*, 1997; Verkhunov, 1997).

The core length is 333 cm. By lithology and granulometric characteristics of sediments, the section is subdivided into three horizons (Gorbarenko *et al.*, 1998). The lower part of the section (220–333 cm) is composed of gray silty mud grading upward into the horizon of greenish gray aleuropelitic mud with an elevated content of siliceous microfossils (120–220 cm). The lower part of the horizon encloses two thin (several millimeters) interbeds of volcanic ash at the depth levels of 210 and 170 cm. The upper part of the core section (0–120 cm) is represented by green pelitic diatomaceous ooze. The section structure and $CaCO_3$, SiO_2, and C_{org} contents in sediments are shown in Figure 2.

Sediment samples for the foraminiferal study (35 in total) were collected from every 10-cm-thick interval. Dry residues (fraction 0.05 mm) were examined under the binocular microscope to determine species composition of benthic foraminifers and to calculate abundance rates of every species (in %) and total abundance of benthic specimens.

In addition, oxygen and carbon isotopic composition in tests of *Uvigerina* spp. (benthic forms) and *Neogloboquadrina pachyderma* sin. (planktonic form) from the interval of 60–333 cm was determined at the Pacific Oceanographic Institute, Russian Academy of Sciences. Seven samples from the levels of 60, 90, 164, 182, 202, 260, and 300 cm were selected for the radiocarbon dating using the AMS technique at the Lawrence Livermore National Laboratory (California, USA). The radiocarbon dates obtained are 2170, 3080, 8780, 9230, 12180, 15950, and 19830 years, respectively (Gorbarenko *et al.*, 1998). The measured age values are reduced for the reservoir-correction factor of the Sea of Okhotsk by subtracting 1100 years (Southon *et al.*, 1993) (Fig. 2).

Planktonic foraminifers previously studied in the same samples made it possible to reconstruct conditions in the surface water layer and to trace main climatic and hydrological events that occurred in the Sea of Okhotsk during the last 20000 years (Chekhovskaya and Basov, 1999). Based on changes in composition of foraminiferal assemblages, periods of the last glaciation (20000–12500 years ago), deglaciation (12500–8000 with a brief well-expressed cooling event of the Younger Dryas, about 10800 years ago), and post-deglaciation (the last 8000 years) were established in the study area.

DISTRIBUTION OF BENTHIC FORAMINIFERS

Benthic foraminifers are found in all examined samples. The total abundance of their tests significantly

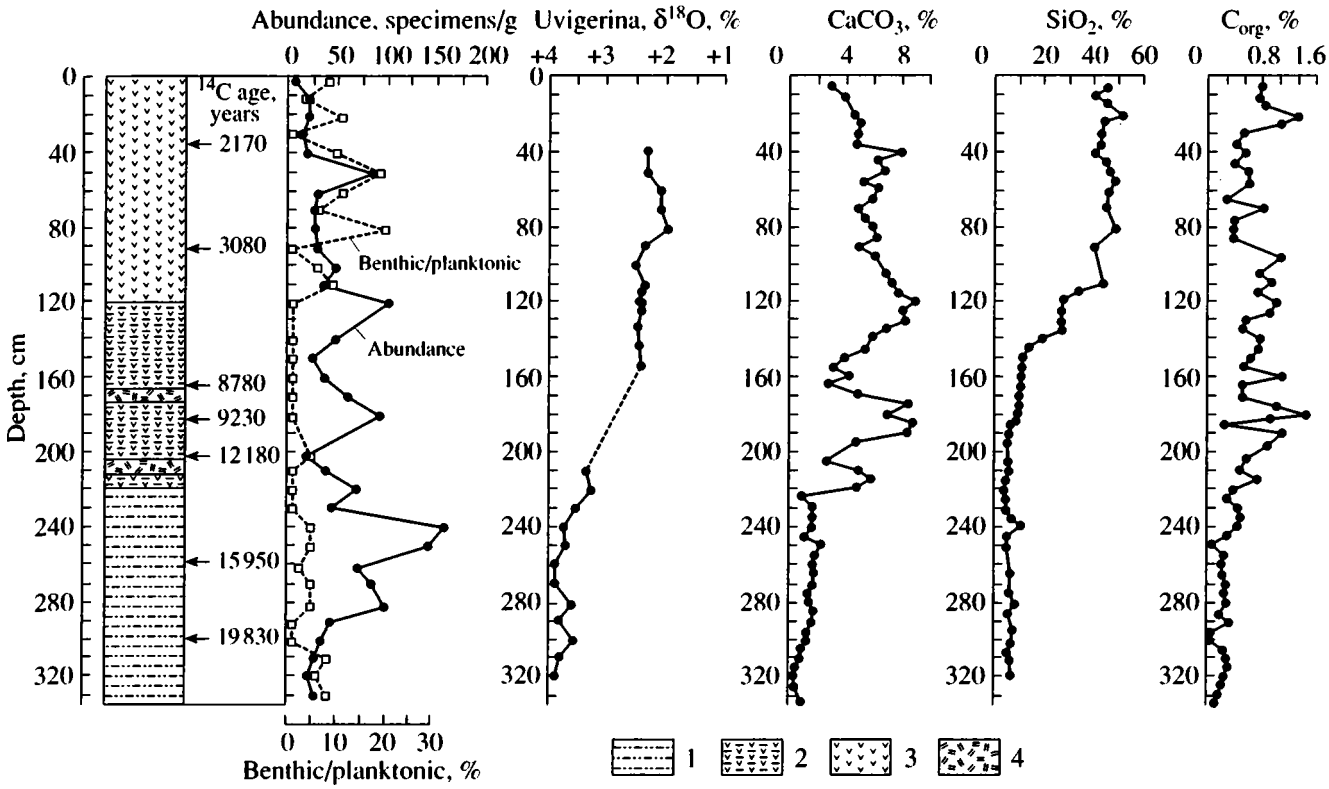

Fig. 2. Lithology, radiocarbon age of sediments, abundance of benthic foraminifers (specimens/gram of dry sediment), their share relative to the total abundance of planktonic and benthic species (%), and content of $CaCO_3$, SiO_2, and C_{org} (%) in sediments of Core V34-90: (1) aleuritic terrigenous mud; (2) aleuropelitic terrigenous–organogenic mud; (3) pelitic organogenic (diatomaceous) ooze; (4) volcanic ash.

varies throughout the section (Fig. 2). The highest abundance (up to 100–150 specimens/gram of a dry sediment) is recorded in the intervals of 250–290, 180–190, 120–130, and 50–60 cm. In other core intervals, the total abundance of benthic foraminifers does not exceed 50 specimens/g. It is noteworthy that the abundance of benthic forms varies along the section in parallel with changes in the $CaCO_3$ content and with abundance of planktonic foraminifers, although the lowermost (230–233 cm) and uppermost (0–50 cm) parts of the section represent an exception. The sediments of the lower part of the section are characterized by the high abundance rate of benthic foraminifers reaching 160 specimens/g of dry sediment, the maximum value for the entire core, despite the low $CaCO_3$ content and low total abundance of planktonic forms in this interval. In the upper part of the section, the peak abundance of benthic foraminifers is recorded in the sediments with the high $CaCO_3$ content, but this is not accompanied by any noticeable increase in the content of planktonic foraminifers.

Benthic foraminifers also show significant compositional variations along the section. Only one species *Alabaminella weddellensis* Earland (often referred as well to the *Eponides* genus) is persistently at a high abundance level, although its proportion in the assemblage also varies throughout the section. The highest share of this species in the assemblage (up to 50% and more) is peculiar of the lower part of the section, in the interval of 220–333 cm, where *Uvigerina senticosa* Cushman, *Cassidulina teretis* Tappan, and *Bolivina subspinescens* Cushman are also sufficiently abundant. Higher in the section, the proportion of *Alabaminella weddellensis* decreases, though its role remains noticeable (Fig. 3).

Most significant changes in composition of benthic foraminifers are characteristic of the level of 223 cm. This level marks appearance of *Valvulineria ochotica* Stschedrina, *Uvigerina peregrina* Cushman, and *Cassidulina laevigata* d'Orbigny, and also the substantially increased share of *Bolivina subspinescens*. Along with *Alabaminella weddellensis*, these species are dominant in the interval of 160–223 cm. Species *Cassidulina teretis* disappears here almost completely. Sediments at the level of 200 cm display a sharp prevalence of *Alabaminella weddellensis* and decreased share of *Uvigerina peregrina* and *Cassidulina laevigata*.

Substantial changes in composition of the foraminiferal assemblage are also observed approximately at the level of 160 cm, where of *Uvigerina peregrina* and *Cassidulina laevigata* disappear, whereas *Cassidulina teretis* becomes again abundant. Dominant species in

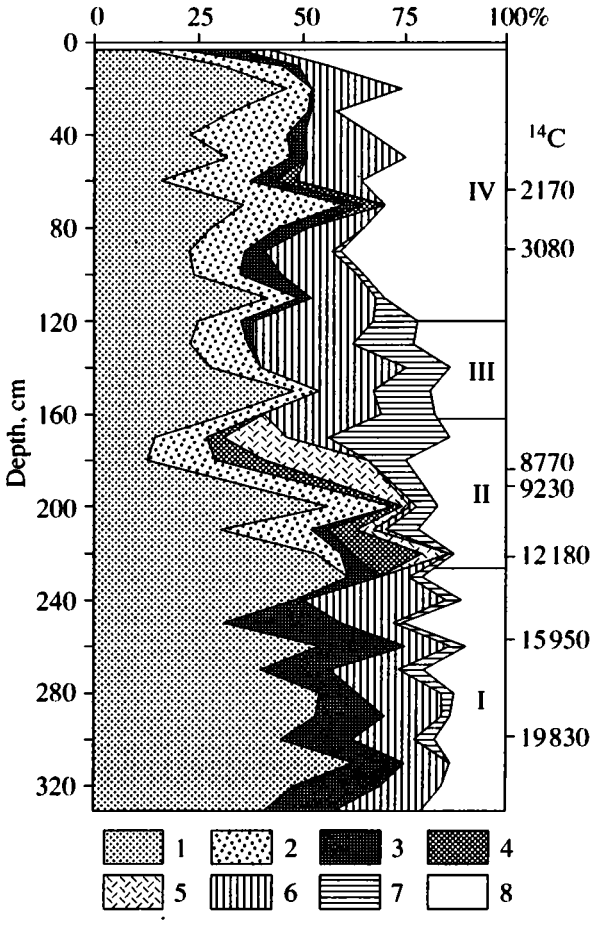

Fig. 3. Changes in composition of dominant species of benthic foraminifers: (1) *Alabaminella weddellensis*; (2) *Valvulineria ochotica*; (3) *Uvigerina senticosa*; (4) *Uvigerina peregrina*; (5) *Cassidulina laevigata*; (6) *Cassidulina teretis*; (7) *Bolivina subspinescens*; (8) other species. Numbers to the right indicate radiocarbon dates (years); roman numbers designate the distinguished assemblages of benthic foraminifers.

the interval of 120–160 cm are represented by *Alabaminella weddellensis, Cassidulina teretis, Bolivina subspinescens*, and *Valvulineria ochotica.*

In the upper part of the section (interval of 0–120 cm), the benthic foraminiferal assemblage consists mainly of *Valvulineria ochotica, Alabaminella weddellensis, Cassidulina teretis*, and *Uvigerina senticosa.* All these species, except for *Valvulineria ochotica*, play a dominant role also in the lower part of the section.

Based on the relative abundance rates of dominant foraminiferal species, four their assemblages are distinguished in the studied section. The latter is divided into intervals of 223–333, 160–223, 120–160, and 0–120 cm dominated by different species (Fig. 3). Correlation of these horizons with the oxygen isotope variations and radiocarbon dates indicates that sediments of the lowermost horizon accumulated during the last glaciation period (2000–12500 years ago). Accumulation of the second horizon corresponds to deglaciation (12500–8000 years ago) and that of two upper horizons to the post-deglaciation period, or to the current interglacial (the last 8000 years).

(I) The *Alabaminella weddellensis–Uvigerina senticosa–Cassidulina teretis* assemblage corresponding to the glacial is registered in the interval of 223–333 cm, where silty mud shows the very low content of $CaCO_3$ (below 2%), SiO_2 (less than 1.0%), and C_{org} (0.3–0.5%).

The total abundance of benthic foraminifers in this horizon varies from 20 specimens/g in its lower part to 150 specimens/g in the upper one corresponding to the interval of 240–250 cm that accumulated in the period of 14–15 ka. The $CaCO_3$ content also increases in the same direction from fractions of percent in the lowermost part of the section to 2% in the interval of 240–250 cm. The SiO_2 and C_{org} contents remain low across the entire horizon, about 10 and 0.3%, respectively. Only the interval of 240–250 cm is characterized by the elevated C_{org} content (0.5%). Benthic foraminifers represent 1–2 to 10% of the total amount of benthic and planktonic species (Fig. 2).

In total, this horizon yielded 52 species of benthic foraminifers, assemblages of which include from 23 to 32 species in a sample. The sharply prevalent species is *Alabaminella weddellensis* whose relative abundance ranges from 30 to 60%. Abundance rates of two other dominant species *Uvigerina senticosa* and *Cassidulina teretis* also vary from 15–20 to 30%, increasing in parallel with the decrease of the *Alabaminella weddellensis* share and, to the contrary, decreasing when the abundance of the latter grows (Fig. 3). Persistent constituents of the assemblage are *Bolivina subspinescens, Elphidium clavatum* Cushman, *E. subarcticim* Cushman, and *Buccella frigida* (Cushman), which are characteristic of some Arctic seas.

(II) The *Valvulineria ochotica–Alabaminella weddellensis–Uvigerina peregrina–Cassidulina laevigata–Bolivina subspinescens* assemblage corresponding to the period of deglaciation is recorded in the interval of 160–223 cm, where aleuropelitic mud shows the relatively high $CaCO_3$ and C_{org} contents from 3 to 9% and from 0.6 to 1.5%, respectively. Minimal concentrations of these components are confined to the interval of 200–204 cm corresponding to the Younger Dryas event. The upper part of the horizon is enriched in SiO_2 whose content amounts to 15% in the interval of 160–170 cm.

The total abundance of the benthic foraminiferal tests in this interval is slightly reduced as compared with the underlying glacial sediments. The peak value of about 120 specimens/g at the level of 180 cm decreases to about 20 specimens/g in the interval of 200–204 cm. The latter is also marked by a minimal species diversity corresponding to 25–32 species/sample. The share of benthic species relative to the total number of foraminiferal tests is about 1%, but it increases to 7% in the interval of 200–204 cm (Fig. 2).

The assemblage of the deglaciation period significantly differs from the glacial one in the taxonomic composition. This is well seen from the reduced relative abundance of *Alabaminella weddellensis* and from disappearance of *Uvigerina senticosa* and *Cassidulina teretis*, the dominant forms of the glacial assemblage. Simultaneously, the assemblage includes some new elements, such as *Valvulineria ochotica, Uvigerina peregrina*, and *Cassidulina laevigata*, species, which play, along with *Alabaminella weddellensis*, a leading role in the assemblage. The share of *Bolivina subspinescens* also noticeably increases. Proportions of dominant species vary throughout the horizon under consideration. In its lower part (interval of 220–204 cm), the dominant species is *Alabaminella weddellensis* (about 30%), and a significant share also belongs to *Valvulineria ochotica, Uvigerina peregrina, Cassidulina laevigata*, and *Bolivina subspinescens*, whose proportions amounts to 25, 20, 7, and 10%, respectively. Higher, in the interval of 200–160 cm, the relative abundance of *Alabaminella weddellensis* is 15% and less, whereas other dominant species represent over 60% of the assemblage. A particularly high relative abundance (up to 30%) is characteristic of *Cassidulina laevigata*. In the uppermost part of the horizon (interval of 170–160 cm), abundance of *Cassidulina teretis* noticeably increases again. The lower and upper parts of the horizon are divided by a layer (interval of 200–204 cm), where the relative abundance of *A. weddellensis* increases to 60–65% becoming as high as in the glacial assemblage, but, in contrast to the latter, this species is accompanied here by *Valvulineria ochotica* and by less abundant *Uvigerina peregrina, Cassidulina laevigata*, and *Bolivina subspinescens* (Fig. 3).

(III) The *Alabaminella weddellensis–Valvulineria ochotica–Cassidulina teretis–Bolivina subspinescens* assemblage is characteristic of the horizon of 120–160 m corresponding to the initial phase of the postdeglaciation period. The assemblage is enclosed in aleuropelitic sediments similar in lithology and appearance to the underlying mud, but differing from it in a slightly lower content of the aleuritic fraction. The $CaCO_3$ and C_{org} contents remain approximately equal to those in glacial sediments, whereas the biogenic silica content increases to 30%.

The total abundance of benthic foraminifers in the sediments of this horizon is comparable with that in underlying sediments (20–100 specimens/g), but their diversity ranging from 30 to 42 species simultaneously increases. The share of benthic species relative to the sum of benthic and planktonic foraminifers is 1–2% (Fig. 2).

The composition of dominant species in the assemblage under consideration substantially changes. *Uvigerina peregrina* and *Cassidulina laevigata* disappeared, whereas *Cassidulina teretis*, the dominant species of the glacial assemblage, appears again to be immediately at the leading position in the assemblage. Species *Alabaminella weddellensis, Valvulineria ochotica*, and *Bolivina subspinescens* continue to play an important role in the considered horizon.

(IV) The *Alabaminella weddellensis–Valvulineria ochotica–Cassidulina teretis–Uvigerina senticosa* assemblage is characteristic of the upper 120-cm-thick core interval of green pelitic diatomaceous ooze. Sediments of this horizon reveal the highest (for the entire section) SiO_2 and $CaCO_3$ contents (up to 50 and 5–9%, respectively). The C_{org} content remains approximately equal to that in underlying sediments (0.7–1.5%).

The abundance of benthic foraminifers in the horizon usually does not exceed 40–50 specimens/g, often decreasing to 15–20 specimens/g, i.e., it is lower than in sediments of the deglaciation and, even, glacial periods. Nonetheless, their share in the total assemblage of foraminifers amounts to 15–20%, being at the maximum relative to other horizons. The diversity varies from 22 to 42 species in a sample.

The group of dominant species is close in composition to that from underlying sediments. Most abundant in the group are *Alabaminella weddellensis, Valvulineria ochotica*, and *Cassidulina teretis*, whereas *Bolivina subspinescens*, the dominant species of the previous assemblage, is replaced by *Uvigerina senticosa*. Almost all these species prevailed also in the glacial assemblage. The sole exception is *Valvulineria ochotica* that is one of the most abundant species in the assemblage reaching sometimes the abundance rate of 25% (Fig. 3). Persistently present are also *Chilostomella oolina* Schwager and *Globobulimina auriculata* (Bailey).

DISCUSSION

Interpretation of habitat environments of the distinguished benthic foraminiferal assemblages and, thus, reconstruction of hydrological parameters of the near-bottom water mass and their changes during the late Pleistocene and Holocene is possible based on the distribution patterns of foraminifers in modern bottom sediments of the Sea of Okhotsk, which are sufficiently well studied (Saidova, 1961, 1975, 1997; Basov and Khusid, 1983a; 1983b). According to available data, the area of the Akademii Nauk Rise, from which the considered core was obtained, is now occupied by the benthic foraminiferal assemblage with dominant *Cassidulina teretis* and *Uvigerina senticosa* commonly associated with *Valvulineria ochotica* and *Alabaminella weddellensis*. The assemblage is widespread in diatomaceous ooze in the central part of the sea and on the Kamchatka and Sakhalin continental slopes in the depth range from 500 to 1500 m, i.e., in areas where the Pacific water mass is a controlling factor. The relative share of dominant species in the assemblage varies depending on the depth. The depth interval of 750–1200 m corresponding to the core of the Pacific water mass with the maximum temperature (about 2.5°C) and

sharp deficiency of dissolved oxygen (up to 0.1 ml/l) is marked by the relative prevalence of *Uvigerina senticosa* and *Valvulineria ochotica*. Below 1200 m, where the water temperature falls down to 2°C or lower and the dissolved oxygen content increases to 1.0 ml/l, the share of *Cassidulina teretis* increases, and *Chilostomella oolina* and *Globobulimina auriculata* appear in the assemblage.

Peripheral areas of the sea with sediments enriched in C_{org} (up to 2% and more) are colonized by the assemblage with dominant *Uvigerina peregrina* always having a high abundance rate in these areas. Persistently present in the assemblage are *Uvigerina senticosa*, *Bolivina subspinescens*, *Valvulineria ochotica*, *Cassidulina laevigata*, and *C. teretis*. Foraminiferal populations with a high abundance of *Uvigerina peregrina*, *Bolivina subspinescens*, and *Cassidulina laevigata* were noted by many researchers as typical of highly productive areas of the World Ocean (Smith, 1964; Phleger and Soutar, 1973; Khusid, 1977, 1979; Sen Gupta and Machain-Castillo, 1993; and others). The distribution of *Cassidulina laevigata* and *C. teretis* is under control of the bottom water temperature. According to some data (Saidova, 1962), *Cassidulina laevigata* prefers bottom areas in the Sea of Okhotsk and northwestern Pacific, above which the water temperature is about 2°C, whereas *C. teretis* is more abundant in areas with colder waters. The high abundance of the latter is also characteristic of modern shelf sediments in the Arctic basin and North Atlantic (Greenland, North, and Barents seas), where the near-bottom temperature is about 0°C (Mackensen and Hald, 1988), as well as the upper Pleistocene sediments in the North Atlantic that accumulated in cooling periods (Feyling-Hansen *et al.*, 1983). Distribution of this species in the Upper Quaternary sediments of the southeastern Sea of Okhotsk is closely connected with the intensity of the warm Pacific water influx into the area (Khusid and Basov, 1999).

The analysis of data on distribution of benthic foraminifers and changes in the composition and structure of their assemblages in the upper Pleistocene–Holocene sediments of the Sea of Okhotsk, with due account for ecological characteristics of modern species, made it possible to trace main hydrological events that occurred in this basin in response to climatic fluctuations during the last 20000 years.

During the terminal phase of the last glaciation period (20000–12500 years ago), hydrological conditions in the bottom layer substantially differed from the modern ones. The isotopic studies revealed that the temperature of bottom water was at the minimum during that phase as compared to other values characterizing the entire period. The corresponding bottom sediments show the very low content of organic matter (C_{org} about 0.5% and less). The composition of dominant species in the glacial assemblage of benthic foraminifers that includes *Alabaminella weddellensis*, *Uvigerina senticosa*, *Cassidulina teretis*, and *Bolivina subspinescens* is close to the modern one, but the assemblage structure shows substantial differences (Fig. 3). This is evident first of all from a sharp preponderance of *Alabaminella weddellensis* whose relative abundance is usually over 50%. In the modern Sea of Okhotsk, the species occurs in all settings though being always subordinate in abundance. In the modern Pacific, it is widespread in oligotrophic areas below 2500 m, where the temperature is less than 2°C and the content of organic matter is low (Saidova, 1975). Development of this species under conditions of the low influx of organic matter (phytoplankton remains) and low temperatures, when metabolic processes decelerate, indicates its ability for a rapid growth to the state of reproductive maturity. This assumption is also supported by peculiar morphological features of *A. weddellensis*: small test dimensions, thin wall, and high number of chambers. Owing to precisely these properties, the species was probably able to support a high population growth at the glacial stage, when the sea was covered by ice almost all the year round, and phytoplankton development was possible only during short summer seasons.

The overall composition of the benthic foraminiferal assemblage in glacial sediments is also indicative of low temperatures near the bottom. An important role in their assemblage belonged at that time to Arctic species *Elphidium clavatum*, *E. subarcticum*, and *Buccella frigida*, which occur persistently, although in small amounts (less than 1%), in glacial sediments. Their relative abundance is several times higher only in the interval of 250–240 cm corresponding to the period of 15000–14000 years ago. The occurrence of these typical shelf species in sediments of the study area can most likely be explained by ice rafting. In this case, the increase in their abundance in the period of 15000 to 14000 years indicates an intensification of this process. This event corresponded approximately to the commencement of ice shield destruction in northern hemisphere about 15000 years ago (Jones, 1991) and to the first, after the glacial maximum, warming episode in the North Atlantic about 14000 years ago (Fairbanks, 1989). In the curve showing variations of the oxygen isotope composition in the *Uvigerina* tests, the event coincides with the negative shift by 0.25‰ as compared with the previous period, i.e., it was probably characterized by a slight increase in the bottom water temperature. Simultaneously, the oxygen isotope composition of planktonic *Neogloboquadrina pachyderma* sin. reflects the lowest temperature of the glacial period under consideration (Gorbarenko *et al.*, 1998). This is also confirmed by a sharp (two–three times) decrease in the content of the subpolar planktonic species *Globigerina bulloides* and by the almost complete disappearance of the dextral variety of *Neogloboquadrina pachyderma* (Chekhovskaya and Basov, 1999).

The hydrological conditions of the period remain unclear. It should be noted that benthic foraminifers

from sediments of the considered interval (240–250 cm) are characterized by a maximum total abundance suggesting their high productivity at the corresponding time. Judging from a slightly increasing content of C_{org} (up to 0.8%) and biogenic SiO_2 (up to 10%) in sediments, the surface water productivity also somewhat increased, probably in response to a slight warming. The latter, however, is not reflected in abundance of planktonic species or in the oxygen isotope composition of their tests.

During the deglaciation period (about 12500–8000 years ago), the bottom water temperature noticeably increased probably owing to the commenced intense influx of the warm Pacific water into the Sea of Okhotsk. Despite the high relative abundance of *Alabaminella weddellensis*, other species such as *Uvigerina senticosa* and *Cassidulina teretis*, which formed often up to 40% of the earlier assemblage, disappear from sediments (Fig. 3). Simultaneously, the abundance of *Bolivina subspinescens* increases and new elements (*Valvulineria ochotica, Uvigerina peregrina, Cassidulina laevigata*) appear to become immediately dominant. All these species are dominant in the entire section of deglaciation sediments, although their share varies at different levels. In the lower part of the horizon (204–223 cm), the relative content of *Alabaminella weddellensis* is approximately equal to the total share of newly appeared species (about 30%). In its upper part (200–160 cm), the proportion of *A. weddellensis* decreases to 15%, whereas *Valvulineria ochotica, Uvigerina peregrina*, and *Cassidulina laevigata* constitute together more than 50% of the assemblage. Especially increased abundance is characteristic of the latter species that, according to Saidova (1961), prefers the water temperature above 2°C. Two parts of the horizon are divided by the interval of 200–204 cm, where the relative abundance of *Alabaminella weddellensis* increases up to 56% to be comparable with that during the glacial, whereas the *Cassidulina laevigata* share falls down to the minimal value (2%). Simultaneously, this interval is marked by a sharp fall in the total abundance of benthic foraminifers (Fig. 2). It is noteworthy that *Cassidulina laevigata* disappears from sediments approximately at the same level in the Core V34-92 obtained from the top of the Akademii Nauk Rise (depth of 985 m), although this species represents one of the dominant taxa in underlying and overlying sediments (Belyaeva and Burmistrova, 1997).

Thus, distribution of benthic foraminifers in sediments of the studied core section indicates the two-step warming during deglaciation. Isotopic investigation of planktonic species *Neogloboquadrina pachyderma* also revealed two negative shifts (Gorbarenko, 1996; Gorbarenko *et al.*, 1998). These warming episodes termed as Terminations T1A and T1B are distinctly recorded in the northwestern Pacific at the time levels of 12.5 and 9.5 ka, respectively (Kallel *et al.*, 1988; Keigwin *et al.*, 1992; Gorbarenko, 1996). The most significant shift toward the lighter oxygen isotope composition (by 0.9‰) occurred 12.5 ka ago. In the Norwegian Sea, this warming event coincides with the commencement of an intense disintegration of the ice cover 12 ka ago (Fairbanks, 1989). The warming phases are divided by a brief cooling episode that is reflected in a higher content of *Alabaminella weddellensis*, decreased abundance of *Cassidulina laevigata*, and in a sharp reduction of the total abundance of benthic foraminifers. The cooling episode is also distinctly manifested in a sharp positive shift of $\delta^{18}O$ measured in tests of *Neogloboquadrina pachyderma* and in a fall of the total planktonic species abundance to the minimum (Chekhovaskaya and Basov, 1999). The episode is correlated with the Younger Dryas cooling event (about 10000 years ago) that is registered by isotopic studies in the North Atlantic (Fairbanks, 1989; Duplessy *et al.*, 1991) and northern Pacific (Kallel *et al.*, 1988; Keigwin *et al.*, 1992; Gorbarenko, 1996).

The deglaciation period is marked by a fall of the total abundance of benthic foraminifers as compared with that of the glacial stage (about 100 versus 160 specimens/g of dry sediment, respectively). Taking into consideration that abundance of benthic foraminifers is dependent of the surface water productivity (e.g., Gooday, 1994), we could expect decrease of the latter during the deglaciation stage. Nonetheless, the total abundance of planktonic foraminiferal species, as compared with that in the glacial period, sharply increased at the same time (Chekhovskaya and Basov, 1999) indicating the enhanced surface water productivity. This assumption is also supported by a significant increase in the C_{org} content in sediments up to 1.5% (Fig. 2). Consequently, the abundance decline of benthic foraminifers during the deglaciation is most likely caused by other factors. On the one hand, this can be explained by the of sedimentation rate growth at the beginning of deglaciation approximately by one third (from 10 to 13 cm/1000 years) owing to the increased influx of both the terrigenous and biogenic material. On the other hand, this could be related to the changes in bottom water conditions. In the study area, the deglaciation period was marked by intensification of dissolution processes (Chekhovskaya and Basov, 1999), which could negatively influence the abundance rate of benthic foraminifers.

The composition of the benthic foraminiferal assemblage indicates a substantial transformation of the hydrochemical regime in the bottom water layer during the deglaciation. The increased abundance of some genera, e.g., of *Uvigerina, Bolivina, Cassidulina, Globobulimina*, and *Valvulineria*, indicates most likely the low content of dissolved oxygen. Many researches (Corliss and Chen, 1988; Corliss, 1991; Sen Gupta and Machain-Castillo, 1993; Gooday, 1994) established that representatives of these genera, dwelling within the highly productive areas in sediments enriched in organic matter, can easily adapt to the oxygen deficiency in the bottom water layer being able to survive, when the oxygen content is 0.1–0.2 ml/l.

The commencement of interglacial conditions about 8500–8000 years ago was marked by a noticeable renewal of the composition of dominant benthic species that indicates further transformation of the bottom water mass. From this time on, the bottom was colonized by a foraminiferal assemblage dominated, in addition to *Alabaminella weddellensis*, by *Valvulineria ochotica*, *Bolivina subspinescens*, and *Cassidulina teretis*. The latter one is widespread in glacial sediments, but is missing from underlying sediments of the deglaciation period, where it is replaced by more thermophilic form *Cassidulina laevigata*. The above-mentioned species retain their dominant position (more than 80% in total) in the interval of 120–160 cm that corresponds approximately to the period of 8000–5000 years. The uppermost sediments of the interval enclose fairly abundant specimens of *Uvigerina senticosa* dominant higher in the section.

The bottom water conditions characteristic of this period are ambiguous for interpretation. The isotopic studies demonstrated a significant reduction of $\delta^{18}O$ values in *Uvigerina* tests (approximately by 1‰) as compared with those characteristic of the deglaciation stage, and this suggests a higher water temperature. The oxygen isotope ratio in tests of the planktonic form *Neogloboquadrina pachyderma* also indicates warming (Gorbarenko *et al.*, 1998). Simultaneously, a high share of *Cassidulina teretis* and complete absence of *C. laevigata* allow, in contrast, an assumption that the bottom water temperature decreased at that time. The conflict resolution lies probably in specific hydrological and hydrochemical conditions in the bottom layer.

It is well known that representatives of the *Cassidulina*, *Bolivina*, and *Valvulineria* dominant in foraminiferal assemblages from the study area are detrivorous species and live in sediments rich on organic matter. They are well adapted to the oxygen-deficient bottom environments surviving when the dissolved oxygen content is 0.1 to 0.2 ml/l (Corliss and Chen, 1988; Corliss, 1991; Sen Gupta and Machain-Castillo, 1993; Gooday, 1994). Prevailing representatives of these genera in the benthic foraminiferal assemblage from sediments of the early phase of the interglacial period could probably indicate a significant fall of the dissolved oxygen content in the bottom water layer. It may be assumed that such conditions resulted from the increased surface water productivity and from the oxygen consumption by oxidation of organic matter sinking to the bottom. The high bioproductivity of surface waters is evident from a high content of C_{org} (up to 1.2%), $CaCO_3$ (up to 8–9%), and biogenic silica in sediments. Concentration of the latter increased progressively from 12% at the beginning of the interglacial period to 30% in the period of 6000–5000 years. Accumulation of fine-grained aleuropelitic mud with a significant admixture of diatoms indicates a weak hydrodynamic activity in the bottom water layer at that time, and this, in combination with the elevated content of organic matter in sediments, resulted in the reduction of dissolved oxygen content in the near-bottom water. Thus, the main factor responsible for development of benthic foraminifers during the early phase of the interglacial period was most likely the deficiency of dissolved oxygen in the near-bottom water layer rather than thermal characteristics of the latter.

Interglacial conditions in the Sea of Okhotsk were conclusively settled about 4000 years ago, when the bottom was populated by the foraminiferal assemblage close in composition to the modern one. Species *Alabaminella weddellensis*, *Uvigerina senticosa*, and *Cassidulina teretis*, which determined the structure of the glacial assemblage, distinctly prevailed among benthic foraminifers during the last 4000 years. The sole exception is *Valvulineria ochotica* that is missing from glacial deposits of the study area being widespread in interglacial sediments. The similarity between glacial and late interglacial foraminiferal assemblages is seen not only in their taxonomic composition. Taking into consideration the difference between sedimentation rates during these two periods (10.3–10.6 and about 30 cm/1000 years, respectively), these assemblages are comparable in productivity of benthic foraminifers. The relevant sediments are also marked by the maximum values of the benthic/planktonic foraminifer abundance ratio.

At the same time, the analyzed structure and other parameters of the foraminiferal assemblages, as well as different lithological characteristics of host sediments, show that bottom environments of the Sea of Okhotsk substantially differed during the last 4000 years from those in the glacial period. First, the high abundance of benthic foraminifers during the glacial stage was conditioned by domination of the cold-resistant epifaunal *Alabaminella weddellensis* that dwells on the sediment surface and adapts easily to short-term outburst of the phytoplankton productivity in the surface water layer (Mackensen, 1992; Gooday, 1994). This and also the absence of *Valvulineria ochotica* in glacial sediments firstly indicate the lower temperature in the bottom water layer during the glacial time as compared with that during the last 4000 years. Second, chemical properties of the near-bottom waters were probably also different to a significant extent during these two periods. Good preservation of planktonic foraminiferal tests, despite their low total abundance in glacial sediments (Chekhovskaya and Basov, 1999), suggests a weak activity of dissolution processes at that time. In this case, the elevated ratio between the benthic and planktonic species abundances is a consequence of the relatively low productivity of planktonic foraminifers. The low biological productivity of the surface water layer during the glacial period is also evident from the minimal C_{org} content in the relevant sediments. To the contrary, the near-bottom water of the late phase of the interglacial period was quite aggressive with respect to calcium carbonate, as it is evident from a high abundance of fragmented tests of planktonic foraminifers in sediments having the high $CaCO_3$ content (Che-

khovskaya and Basov, 1999). Hence, the higher (up to 15%) relative share of benthic species in the whole foraminiferal community is a result of their higher resistance to dissolution as compared with that of planktonic forms, but not a consequence of low productivity of the latter, as it was characteristic of the glacial period. Intensification of dissolution processes at that time was most likely related to the low content of dissolved oxygen in the near-bottom water layer, where it was consumed during oxidation of large amounts of organic matter precipitated from the highly productive surface waters to the bottom, hydrodynamics above which was weak. The latter is evident from lithology (pelitic diatomaceous ooze) and high content of SiO_2, $CaCO_3$, and C_{org} in sediments (up to 50, 8, and 1.4%, respectively), as well as from a sharp increase of sedimentation rates (up to 33 cm/1000 years) in response to the high influx of biogenic components.

The high general bioproductivity of the surface water during the late interglacial period is also reflected in a higher productivity of benthic foraminifers. Despite the total abundance of benthic species (with due account for increased sedimentation rates) in interglacial diatomaceous ooze comparable with that in terrigenous sediments of the glacial period, the elevated productivity of the former is inferable from the greater abundance of benthic species with large tests. For instance, the test of *Valvulineria ochotica*, one of the dominant species in the interglacial assemblage, is 4–5 times larger than that of *Alabaminella weddellensis*, the main species of the glacial period. Similar proportions in dimensions are also characteristic of *Cassidulina teretis* and *Alabaminella weddellensis* tests.

CONCLUSION

The upper Pleistocene–Holocene sediments in the central part of the Sea of Okhotsk enclose four assemblages of benthic foraminifers, which have different dominant species and successively replace each other upward in the section. These are (1) the *Alabaminella weddellensis–Uvigerina senticosa–Cassidulina teretis* (interval of 223–333 cm), (2) *Alabaminella weddellensis–Valvulineria ochotica–Uvigerina peregrina–Cassidulina laevigata* (interval of 160–223 cm), (3) *Alabaminella weddellensis–Valvulineria ochotica–Cassidulina teretis–Bolivina subspinescens* (interval of 120–160 cm), and (4) *Alabaminella weddellensis–Valvulineria ochotica–Cassidulina teretis– Uvigerina senticosa* (interval of 0–120 cm) assemblages.

Our analysis of the taxonomic composition of the distinguished benthic foraminiferal assemblages and corresponding lithological data made it possible to trace evolution of bottom conditions in the Akademii Nauk Rise (the central part of the Sea of Okhotsk) during the last 20000 years. The established changes in composition and structure of foraminiferal assemblages reflect the successive replacement of glacial conditions (20000 to 12500 years ago) first by the deglaciation environments (12500 to 8000 years ago), two phases of which are divided by the distinct cooling event of the Younger Dryas (about 10000–9500 years ago), and then by the current interglacial conditions commenced approximately 8000 years ago. This climatic reconstruction is well consistent with the results of the oxygen isotope study (Gorbarenko *et al.*, 1998) and with data on distribution of planktonic foraminifers in the same core (Chekhovskaya and Basov, 1999).

The most significant changes in composition of the benthic foraminiferal assemblage occurred during the deglaciation and at the beginning of the current interglacial period, when they obviously were related to the less stable hydrological and hydrochemical conditions in the bottom water layer as compared to those characterizing the preceding and succeeding periods.

Noteworthy is a substantial similarity between the glacial assemblage and that characteristic of the last 4000 years. Most of principal species of the glacial assemblage sharply dominate also among foraminifers of the late interglacial phase. Simultaneously, the structure and other parameters of foraminiferal assemblages, as well as different lithological characteristics, show that environments near the bottom of the Sea of Okhotsk during the late interglacial phase substantially differed from those existed in the glacial period. The bottom water layer of the interglacial time probably had a higher temperature, as it is evident from the dominant role of *Valvulineria ochotica* missing from glacial sediments and from the decreased share of deep-water species *Alabaminella weddellensis*. In addition, it differed also in the chemical composition being more aggressive relative to calcium carbonate. Intensification of dissolution processes at the proper time was most likely related to the low content of dissolved oxygen in the bottom water layer because of a high bioproductivity of surface waters that triggered the high influx of organic matter to the bottom, above which hydrodynamics was weak. The increased abundance of benthic foraminiferal species with large tests, e.g., of *Valvulineria ochotica, Cassidulina teretis*, and others, also reflects the high bioproductivity of the surface water layer during the interglacial stage. This is also supported by composition of sediments (pelitic diatomaceous ooze) having high contents of SiO_2, $CaCO_3$, and C_{org} (up to 50, 8, and 1.4%, respectively), and by sharply increased sedimentation rates (up to 33 cm/1000 years) owing to the influx of organogenic components.

Distribution patterns of benthic foraminifer in upper Pleistocene–Holocene sediments of the Akademii Nauk Rise and the results of their study in coeval sediments of Core V34-98 in the southeastern Sea of Okhotsk (Khusid and Basov, 1999) demonstrate synchronous secular changes in assemblages despite the essentially different composition of their dominant species. This common trend characterizing different parts of the Sea of Okhotsk indicates that hydrological and hydrochemical changes in the bottom water layer were

controlled by climatic fluctuations. The different composition of dominant species in two areas was determined by different geographical position of the latter and, consequently, by the different degree of influence of the Pacific water mass penetrating into the Sea of Okhotsk via the Kruzenshtern and Chetvertyi straits crossing the northern part of the Kuril island arc.

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First Finds of Paleogene Nannoplankton in Sakhalin

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INTRODUCTION

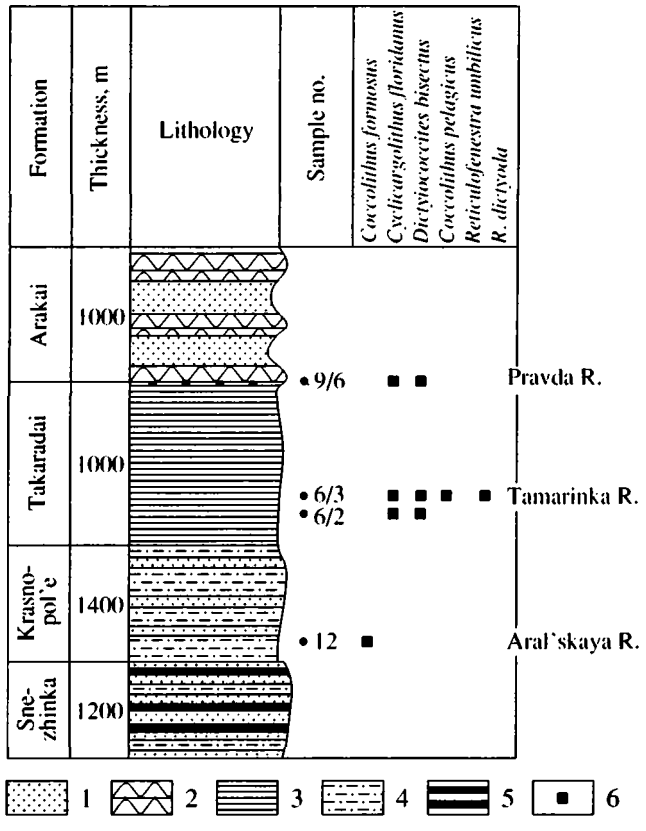
Despite the intense investigations of Cenozoic deposits in Sakhalin during several decades, many problems of Paleogene stratigraphy remain unsolved here (*Geologiya...*, 1970). For instance, ages of Paleogene subdivisions (in particular, of Snezhinka, Krasnopol'e, and, to a lesser extent, of Takaradai and Arakai formations) are inadequately known until now, because remains of planktonic organisms have not been discovered in this interval (except for some sections of the Pogranichnyi district, where Oligocene diatoms are distinguished). During the field work of 1997 in the southwestern Sakhalin, where the Paleogene sequence is most complete, Gladenkov collected 60 rock samples studied afterward in micropaleontological aspect by Shcherbinina, who recognized that some samples bear nannoplankton that is described in this brief communication.

STRATIGRAPHIC POSITIONS OF NANNOPLANKTON ASSEMBLAGES

Nannoplankton is detected in rocks of the Krasnopol'e, Takaradai, and Arakai formations accepted as corresponding in age to the middle Eocene, upper Eocene, and Oligocene, respectively (*Resheniya...*, 1998). The distinguished nannoplankton assemblages are of impoverished taxonomic composition, but they elucidate further the paleontological characteristics of the mentioned formations.

In the Aral'skaya River section, continental deposits of the Snezhinka Formation (Paleocene–basal Eocene) underlie sandstones of the Krasnopol'e Formation. Sandstones are massive, rigid, greenish gray in color, and medium-grained in their texture. They are intercalated with conglomerate and black shale interbeds. The only nannoplankton species *Coccolithus formosus* (Kamptner) Wise was detected in the lower part of the section (about 10 m thick), where beds bearing *Ostrea* are located. The distribution range of this species spans the Eocene and basal Oligocene.

In the Tamarinka River section, the upper sandstone–siltstone member of the Krasnopol'e Formation is overlain by siltstones and shales of the Takaradai Formation. The latter are black, firm, and vaguely laminated. They enclose carbonate concretions that are usually small in size (up to 5 cm across) and locally as large as 0.5 × 1 m. The concretions yield molluscan remains of the *Cardium, Thiasyra*, and some other genera. The nannoplankton assemblage from the lower part of the Takaradai Formation consists of species having wide stratigraphic ranges. Nevertheless, *Reticulofenestra dictyoda* (Deflandre) Stradner and *Dictyococcites bisectus* (Hay, Mohler and Wide) Burky and Percival, which coexist in the assemblage, indicate that the host



Composite stratigraphic section of Paleogene deposits in Sakhalin and levels of samples bearing nannoplankton: (1) sandstone; (2) tuff; (3) shale; (4) siltstone; (5) coal measures; (6) occurrence levels of nannoplankton species.

rocks correspond most likely to the middle Eocene *Reticulofenestra umbilica* Zone (CP 14). We do not exclude as well that the assemblage interval spans, in addition, an upper part of the *Discoaster barbadiensis* Zone (CP 15) of the upper Eocene.

Rocks of the Arakai Formation exposed along the Pravda River are represented by sandstones and green massive lithoclastic tuffs of psephitic texture, which overlie black siltstones of the Takaradai Formation. Samples from this unit yielded sporadic specimens of *Cyclicargolithus floridanus* (Roth and Hay) Burky and *Dictyococcites bisectus* (Hay, Mohler and Wide) Burly and Percival, which concurrently occur within the interval from the uppermost middle Eocene (zone CP 14) to the upper Oligocene.

CONCLUSION

Nannoplankton remains detected in the Paleogene reference sections of the southwestern Sakhalin are rather meaningful at the moment. First, they imply a more precise age determination for the particular levels of the regional Paleogene (e.g., the identification of the middle Eocene deposits at the base of the Takaradai Formation). Second, some of discovered nannoplankton species coexist with benthic fossil assemblages widespread in Sakhalin, and, consequently, the latter can be more confidently used as the age markers. Finally, the occurring nannoplankton suggests that the Paleogene basins of the southern Sakhalin were directly connected with the open ocean. The nannoplankton species from the studied samples are typical of high northern latitudes. For instance, the distinguished nannoplankton assemblage of the middle Eocene species is well correlative with the coeval assemblage recovered at the DSDP Site 192A (Leg 19, Guyot Meiji).

We also should mention that the nannoplankton assemblage from the Takaradai Formation is more diverse than others distinguished in the studied samples, and this may suggest a higher sea-level stand during the middle Eocene as compared to that during the accumulation time of underlying and overlying deposits. This validates the assumed extensive character of the Bartonian transgression (Shcherbinina, 1997) that left records in other areas of the Far East, par example, in eastern Kamchatka.

In general, the further micropaleontological study of Paleogene deposits in Sakhalin appears to be perspective in view of the discussed finds of nannoplankton.

Reviewer I.A. Basov

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